Comprehensive Water Resources Management Plan (CWRMP)

APPENDIX G

Volume 4 of 5
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INDIRECT POTABLE REUSE WORKING GROUP

Acton Board of Health - Telephone (978) 264-9634

FINAL REPORT

OF THE

ACTON INDIRECT POTABLE REUSE

WORKING GROUP

NOVEMBER 15, 2005

Executive Summary

Indirect Potable Reuse, which is groundwater recharge via surface or subsurface disposal in order to augment a potable aquifer, has been in practice across the United States for many years in both planned and unplanned fashions. In Massachusetts, according to the Reclaimed Water regulations now under review, Indirect Potable Reuse would be defined as a discharge of highly treated wastewater treatment plant effluent into the Zone II[1] of a wellfield, with no less than a one year travel time[2] from the point of discharge to the point of intake of the well(s), under normal hydrologic conditions.

The Indirect Potable Reuse Group, which met during the summer and early fall of 2005, evaluated information from regulatory and academic sources in an effort to explore the topic for possible future implementation to help solve water resources management difficulties in Acton.

After much discussion, four major areas of concern emerged:

1) Detection, removal and potential health effects of multiple classes of emerging contaminants
2) Timing of implementation in regards to technological, regulatory, and political timelines
3) Comparison of centralized Indirect Potable Reuse in one wellfield versus decentralized Indirect Potable Reuse in multiple wellfields
4) Coupling implementation with increased water conservation and emerging contaminant source reduction efforts

These four areas represent the foci of the unanswered questions regarding Indirect Potable Reuse and its potential for implementation in Acton. Knowing that a great percentage of these questions need answers, the Group developed a series of four recommendations through which the desired information may be discovered.

The recommendations of the Group are as follows:

1) Inclusion of the concept as a possible solution in the Comprehensive Water Resources Management Plan.

2) Continue to monitor academic and regulatory developments with Indirect Potable Reuse and their possible impact on Acton.

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[1] Zone II – that area of an aquifer which contributes water to a well under the most severe pumping and recharge conditions that can be realistically anticipated

[2] Travel Time – a figure, calculated by computer modeling, which closely approximates the amount of time a water molecule will take to travel from one point to another in the ground under normal hydrologic conditions.

3) Development of a targeted public outreach and education program related to Indirect Potable Reuse, which could include the provision, if feasible and accepted by the community, of a small-scale pilot study through which "local" answers to important questions may be obtained.

4) In the event Indirect Potable Reuse is chosen for further study by the Town, a standing committee should be seated to direct these efforts. This committee should be similar in makeup to the Sewer Action Committee.

Group Report

Background

The Acton Indirect Potable Reuse Working Group was formed in May, 2005, as a sub-group of the Citizens Advisory Committee (CAC) for the Comprehensive Water Resources Management Plan (CWRMP). The Group was tasked with the evaluation of the concept of Indirect Potable Reuse, prior to any consideration of its implementation within Acton. The Group performed its duties under the following mission statement:

> "To evaluate the potential feasibility of the implementation of Indirect Potable Reuse of highly treated Wastewater Treatment Plant effluent through a discharge to the Zone II of a wellfield; the group will examine the issue from the "human" perspective, looking at the political and public relations impacts of any proposal. Those impacts can then be used to determine whether this concept is feasible as a discharge option within Acton."

The Group members are:

Art Gagne' –	Member of the CAC
Eric Hilfer –	ACES representative and member of the CAC
Joanne Bissetta –	Member of the Acton Board of Health
Greta Eckhardt –	Acton Resident
Pat Cumings –	Member of the CAC

Indirect Potable Reuse – The Concept

The reclamation of treated wastewater as a viable resource has been in practice, in many fashions, for over 50 years around the world. Most projects utilizing Indirect Potable Reuse are located in the western and southwestern United States. The closest planned project of significant size to Acton is the Upper Occoquan Sewage Authority, in suburban Washington D.C., which discharges highly treated effluent into a drinking water reservoir. Interest in Indirect Potable Reuse is growing as the grim picture of the scarcity of the world's water resources emerges. More and more communities are looking to innovative solutions, which allow them to recharge their own aquifers with the wastewater they are producing, thereby preserving the local hydrologic cycle.

Indirect Potable Reuse is only one facet of the larger concept of reclaimed water use. This holistic approach to preservation of the local hydrologic cycle includes reuse options for irrigation – residential, commercial, and agricultural; industrial cooling systems; process water in manufacturing facilities; toilet flushing; snowmaking; and fire protection systems. As greater awareness is achieved in regards to the growing scarcity of water resources, water reclamation practices, like Indirect Potable Reuse, are growing in popularity.

Acton CWRMP

The Acton Comprehensive Water Resources Management Plan (CWRMP) was undertaken as part of the acceptance of the Middle Fort Pond Brook Sewer Project by the Massachusetts Department of Environmental Protection (DEP); to determine the wastewater disposal needs for the entire Town, along with the integrated planning necessary to protect Acton's vital liquid resources for the next 20 years.

The CWRMP is guided by two groups working jointly to develop a cohesive plan. The Project Team – consisting of Acton Health Department staff and Woodard and Curran, Inc. engineers and scientists; and the Citizens Advisory Committee – a group of local stakeholders appointed by the Acton Board of Selectmen to represent the broadest possible range of views in regards to Acton's water resources.

As part of the project, wastewater disposal options were evaluated for centralized and decentralized sewer projects of varying sizes. As Acton is both regulatorily and environmentally limited for surface discharge locations, subsurface discharge must be the primary option examined. Subsurface disposal of treated wastewater requires soils with high permeability in order to efficiently dispose of the effluent from both a cost and footprint perspective. As Acton is solely reliant on groundwater aquifers for its public water supply and those aquifers are located in the most permeable soils, the concept of Indirect Potable Reuse was a concept that could not be ignored as a part of a 20 year water resources management plan.

Indirect Potable Reuse Working Group

A sub-group of the Citizens Advisory Committee was formed in May of 2005 to further examine the issues surrounding Indirect Potable Reuse. This group was established to bring together local stakeholders with a variety of viewpoints.

The group received information packets, consisting of published educational journal articles, copies of government-produced information, and newspaper articles all directly related to Indirect Potable Reuse. Copies of these packets are included in Appendix A of this report. The group met during the summer of 2005, to discuss the issues related to Indirect Potable Reuse in accordance with the group's mission statement.

Discussion

After a review of the academic and professional research presented, the group delineated four major areas of concern, each containing topics requiring further research. These four major areas of concern are:

1) Detection, removal and potential health effects of multiple classes of emerging contaminants
2) Timing of implementation in regards to technological, regulatory, and political timelines
3) Comparison of centralized Indirect Potable Reuse in one wellfield versus decentralized Indirect Potable Reuse in multiple wellfields
4) Coupling implementation with increased water conservation and emerging contaminant source reduction efforts

Detection and removal of multiple classes of emerging contaminants

Current research by multiple educational and governmental institutions have identified new classes of emerging contaminants in wastewaters, drinking waters, groundwaters, and surface waters. While research into the possible health effects of these categories of contaminants is ongoing, the absence of concrete toxicological and medical data cannot be ignored. These new classes of contaminants include pharmaceuticals, personal care products, their metabolites and their by-products. Some commonly identified compounds are: Triclosan – an antibiotic found in various antibacterial household products; Caffeine; and Estradiol – one of the key hormones in oral contraceptives.

Studies in Europe, Australia, and the United States are in varying stages of completion in regards to the prevalence of these compounds in wastewater treatment plant influent and effluent. The Town of Acton is participating in one of these studies, sponsored by the Johns Hopkins Bloomberg School of Public Health. Further information on this study is included in Appendix B. This study will report the prevalence and concentration of many of the most common classes of these emerging contaminants, allowing the Town to develop a baseline against which to measure future treatment and disposal options. Separate studies are evaluating the capacity of different wastewater treatment technologies and processes to reduce or eliminate these compounds from the waste stream. Initial results of both sets of studies are presented in some of the articles attached to this report in Appendix A. It must be noted, that as with all academic efforts in the scientific realm, these studies are part of a continuum of discovery following a three-step process: detection, assessment of health risks, development of removal strategies.

Timing of implementation in regards to technological, regulatory, and political timelines

Further pursuit of Indirect Potable Reuse as a reclaimed water strategy will require funding that is not currently allocated within the Comprehensive Water Resources Management Plan. The disbursement of this funding will be at the discretion of the citizens of Acton. While economics will affect the local progression of Indirect Potable Reuse, acceptance of IPR at the state and federal levels will also greatly impact any possible implementation or exploration.

As have been shown by other reclaimed water projects around the U.S., a significant public participation and education campaign must be successfully mounted as the first step of any plan. In Acton, this campaign should be spearheaded by an elected or appointed Town official, not a staff member. It is important that the residents of Acton sufficiently understand the concept of Indirect Potable Reuse so that they may both collectively and individually accept or reject the proposal. This local acceptance must also fit into the Town's broader water resources management strategy in regards to the treatment and disposal capacity necessary to provide a solution to the designated needs areas.

Developments on the regulatory front may have the greatest impact on the possibilities for implementation of Indirect Potable Reuse in Acton. The Commonwealth of Massachusetts is currently developing a new set of Reclaimed Water Regulations, which will govern the reuse of highly treated wastewater in a variety of modalities. Indirect Potable Reuse will, of course, be included as a component of these regulations. These regulations will govern the effluent quality required for an Indirect Potable Reuse discharge, and the economic implications of the level of treatment may be the ultimate determining factor in implementation.

From a technological standpoint, the field of wastewater treatment advances each day in its ability to reduce various compounds to increasingly lower concentrations in treatment plant effluent for reuse projects. While it is impossible to predict what effluent limitations would be placed on any proposed Indirect Potable Reuse project in Acton sometime in the future, it can be expected that proven technologies will be available to meet those limits. The current wastewater treatment plant on Adams Street is discharging some of the highest quality effluent in the Commonwealth. The plant consistently discharges effluent with a Total Nitrogen of less than 3 mg/L (where the EPA drinking water standard is 10 mg/L) and 0 colonies of fecal coliform bacteria. These two contaminants, total nitrogen and fecal coliform bacteria, are two of the most important health-impacting contaminants in the drinking water standards as they relate to wastewater treatment. A caveat to this section would be the inclusion of any classes of emerging contaminants in effluent limitations. As stated previously, studies are still underway to determine which treatment process will most efficiently remove which classes of compounds. Further study would be required, possibly at the local level, in order to determine the best course of action in this case.

Comparison of centralized Indirect Potable Reuse in one wellfield versus decentralized Indirect Potable Reuse in multiple wellfields

The Town of Acton receives 95% of its drinking water from the five Acton Water District wellfields located across the community (see figure 1). As the implementation of Indirect Potable Reuse is evaluated against the needs areas identified in the Comprehensive Water Resources Management Plan, the possibility of lesser discharges spread across multiple wellfields should also be considered. This could allow for broader basin-wide recharge, which could be a benefit to stream flow; and it could also allow for greater proliferation of offsite wastewater disposal solutions for needs areas across Acton.

Coupling implementation with increased water conservation and emerging contaminant source reduction efforts

The possible implementation of an Indirect Potable Reuse project in Acton, and the public participation and education campaign that would precede such a project, could offer a unique outreach opportunities to promote citizen involvement in the protection of water resources. Awareness of the consequences of waterborne disposal of personal care products and pharmaceuticals could lead to a reduction of those products which, along with their metabolites and by-products, make up the classes of emerging contaminants mentioned previously, in the waste stream. As with any other water resources based initiative, it would offer the opportunity to augment the already successful education efforts undertaken by the Acton Water District.

Recommendations

As the Town looks towards the future, all options for beneficial reclamation of wastewater must be evaluated to provide solutions for the 2/3's of the Town identified as having a need for an off-site wastewater disposal solution. This includes Indirect Potable Reuse. No possible solution should be discarded prior to an intensive, citizen-driven, review process.

The group recognizes the contribution that Indirect Potable Reuse could make to the water resource management efforts in Acton. It could serve to recharge aquifers within "stressed" basins and it addresses one of the primary components of the Massachusetts Water Policy, which encourages "keeping water local" by preserving the local hydrologic cycle. Through its deliberations, the group is aware of a number of unanswered questions under each of the four major topic areas.

1) Detection, removal and potential health effects of multiple classes of emerging contaminants
2) Timing of implementation in regards to technological, regulatory, and political timelines
3) Comparison of centralized Indirect Potable Reuse in one wellfield versus decentralized Indirect Potable Reuse in multiple wellfields
4) Coupling implementation with increased water conservation and emerging contaminant source reduction efforts

As with any major environmental decision, the Town must weigh the risks against the benefits and determine whether to progress forward.

The "local" answers to the questions that arise under these four areas may only be fully answered with a small-scale pilot project developed under close coordination with EPA, DEP, academia, and local officials. This project, if feasible, would serve to provide more

specific answers to many questions, for which the answers may currently come from project implemented in the Western United States. This pilot project would require funding appropriations, and would be subject to the approval of elected officials and their constituents in Acton.
Should the Town choose to further explore implementation of Indirect Potable Reuse, a permanent committee, similar to the Sewer Action Committee, should be appointed by the Board of Selectmen to further evaluate implementation options. This committee should be chaired by an elected or appointed town official who is also a resident of the community. It should include representation from, at least, the following stakeholders:

- Acton Board of Selectmen
- Acton Board of Health
- Acton Citizens for Environmental Safety
- Acton Planning Board
- Acton Water District
- Acton Conservation Commission
- The current incarnation of the Wastewater Citizens Advisory Committee
- Residents from those areas who will benefit from the additional disposal capacity
- Acton residents-at-large

This committee should work with the Town's consultants to cultivate a public participation and education plan devoted to Indirect Potable Reuse, and if the response is positive, should work to bring the project to fruition.

Indirect Potable Reuse, as a concept, holds much promise, not only for the Town of Acton, but for many other communities across New England, as the reality of the scarcity of our liquid reserves becomes readily apparent.

APPENDIX A

INFORMATIONAL PACKETS FROM MEETINGS

MEETING MINUTES

ACTON BOARD OF HEALTH

Douglas Halley
Health Director

472 Main Street
Acton, MA 01720

Telephone 978-264-9634
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Town of Acton
Comprehensive Water Resources Management Plan
Citizens Advisory Committee
Indirect Potable Reuse Working Group

Meeting #1
6/1/2005
Acton Town Hall, Room 126

Call to Order 7pm

I. Introductions

II. Working Group Mission Statement
--Comments from members

III. Timeline

IV. Goals

V. IPR Q&A

VI. Set meeting schedule

Adjourn by 830pm

MEMORANDUM

Acton Board of Health - Telephone (978) 264-9634

TO: Members of the Reuse Working Group

FROM: Brent L. Reagor, R.S.

RE: Info Packet
First Meeting Date

DATE: May 13, 2005

Enclosed with this memo you will find ~50 pages selected from the 2004 EPA Guidelines for Water Reuse. These are the pertinent pages dealing directly with the concept of Indirect Potable Reuse. This is your "master packet" for the duration of the sub-group. This packet will serve as a general reference, and as an introduction to the concepts we will discuss. If you have any questions about the content, please get in touch with me.

I would like to schedule the first meeting for June 1st or 2nd. I will send out an email on Monday, May 16 regarding this. I expect the meeting to start around 7 pm (or earlier if that suits everyone) and last 1.5 – 2 hours.

Welcome aboard!

2.6.3 Groundwater Recharge for Indirect Potable Reuse

As mentioned in Section 2.5.1, Methods of Groundwater Recharge, groundwater recharge via surface spreading or injection has long been used to augment potable aquifers. Although both planned and unplanned recharge into potable aquifers has occurred for many years, few health-related studies have been undertaken. The most comprehensive health effects study of an existing groundwater recharge project was carried out in Los Angeles County, California, in response to uncertainties about the health consequences of recharge for potable use raised by a California Consulting Panel in 1975-76.

In November 1978, the County Sanitation Districts of Los Angeles County (Districts) initiated the "Health Effects Study," a $1.4-million-project designed to evaluate the health effects of using treated wastewater for groundwater recharge based on the recommendations of the 1976 Consulting Panel. The focus of the study was the Montebello Forebay Groundwater Replenishment Project, located within the Central Groundwater Basin in Los Angeles County, California. Since 1962, the Districts' reclaimed water has been blended with imported river water (Colorado River and State Project water) and local stormwater runoff, and used for replenishment purposes. The project is managed by the Water Replenishment District of Southern California (WRD) and is operated by the Los Angeles County Department of Public Works. The Central Groundwater Basin is adjudicated; 85 groundwater agencies operate over 400 active wells. Water is percolated into the groundwater using 2 sets of spreading grounds: (1) the Rio Hondo Spreading Grounds consist of 570 acres (200 hectares) with 20 individual basins and (2) the San Gabriel River Spreading Grounds consist of 128 acres (52 hectares) with 3 individual basins and portions of the river. The spreading basins are operated under a wetting/drying cycle designed to optimize inflow and discourage the development of vectors.

From 1962 to 1977, the water used for replenishment was disinfected secondary effluent. Filtration (dual-media or mono-media) was added later to enhance virus inactivation during final disinfection. By 1978, the amount of reclaimed water spread averaged about 8.6 billion gallons per year (33 x 10^3 m^3 per year) or 16 percent of the total inflow to the groundwater basin with no more than about 10.7 billion gallons (40 million m^3) of reclaimed water spread in any year. The percentage of reclaimed water contained in the extracted potable water supply ranged from 0 to 11 percent on a long-term (1962-1977) basis (Crook *et al.*, 1990).

The primary goal of the Health Effects Study was to provide information for use by health and regulatory authorities to determine if the use of reclaimed water for the Montebello Forebay Project should be maintained at the present level, cut back, or expanded. Specific objectives were to determine if the historical level of reuse had adversely affected groundwater quality or human health, and to estimate the relative impact of the different replenishment sources on groundwater quality. Specific research tasks included:

- Water quality characterizations of the replenishment sources and groundwater in terms of their microbiological and chemical content.
- Toxicological and chemical studies of the replenishment sources and groundwater to isolate and identify organic constituents of possible health significance
- Field studies to evaluate the efficacy of soil for attenuating chemicals in reclaimed water
- Hydrogeologic studies to determine the movement of reclaimed water through groundwater and the relative contribution of reclaimed water to municipal water supplies
- Epidemiologic studies of populations ingesting reclaimed water to determine whether their health characteristics differed significantly from a demographically similar control population

During the course of the study, a technical advisory committee and a peer review committee reviewed findings and interpretations. The final project report was completed in March, 1984 as summarized by Nellor *et al.* in 1985. The results of the study did not demonstrate any measurable adverse effects on either the area groundwater or health of the people ingesting the water. Although the study was not designed to provide data for evaluating the impact of an increase in the proportion of reclaimed water used for replenishment, the results did suggest that a closely monitored expansion could be implemented.

In 1986, the State Water Resources Control Board, Department of Water Resources and Department of Health Services established a Scientific Advisory Panel on Groundwater Recharge to review the report and other pertinent information. The Panel concluded that it was comfortable with the safety of the product water and the continuation of the Montebello Forebay Project. The Panel felt that the risks, if any, were small and probably not dissimilar from those that could be hypothesized for commonly used surface waters.

Based on the results of the Health Effects Study and recommendations of the Scientific Advisory Panel, the Regional Water Quality Control Board in 1987 authorized an increase in the annual quantity of reclaimed water to be used for replenishment from 32,700 acre-feet per year to 50,000 acre-feet per year (20,270 gpm to 31,000 gpm or 1,280 to 1,955 l/s). In 1991, water reclamation requirements for the project were revised to allow for recharge up to 60,000 acre-feet per year (37,200 gpm or 2,350 l/s) and 50 percent reclaimed water in any one year as long as the running 3-year total did not exceed 150,000 acre-feet per year (93,000 gpm or 5,870 l/s) or 35 percent reclaimed water. The average amount of reclaimed water spread each year is about 50,000 acre-feet per year (31,000 gpm or 1,955 l/s). Continued evaluation of the project is being provided by an extensive sampling and monitoring program, and by supplemental research projects pertaining to percolation effects, epidemiology, and microbiology.

The Rand Corporation has conducted additional health studies for the project as part of an ongoing effort to monitor the health of those consuming reclaimed water in Los Angeles County (Sloss *et al.*, 1996 and Sloss *et. al.*, 1999). These studies looked at health outcomes for 900,000 people in the Central Groundwater Basin who are receiving some reclaimed water in their household water supplies. These people account for more than 10 percent of the population of Los Angeles County. To compare health characteristics, a control area of 700,000 people that had similar demographic and socioeconomic characteristics was selected, but did not receive reclaimed water. The results from these studies have found that, after almost 30 years of groundwater recharge, there is no association between reclaimed water and higher rates of cancer, mortality, infectious disease, or adverse birth outcomes.

The Districts, along with water and wastewater agencies and researchers in 3 western states, are currently conducting research to evaluate the biological, chemical, and physical treatment processes that occur naturally as the reclaimed water passes through the soil on the way to the groundwater. The SAT Project was developed to better understand the impact of SAT on water quality in terms of chemical and microbial pollutants (see Case Study 2.7.16). This work will continue to address emerging issues such as the occurrence and significance of pharmaceutically active compounds (including endocrine disruptors and new disinfection byproducts) and standardized monitoring techniques capable of determining pathogen viability. The Groundwater Replenishment (GWR) System is an innovative approach to keeping the Orange County, California, groundwater basin a reliable source for meeting the region's future potable water needs (Chalmers *et al.*, 2003). A joint program of the Orange County Water District (OCWD) and the Orange County Sanitation District (OCSD), the GWR System will protect the groundwater from further degradation due to seawater intrusion and supplement existing water supplies by providing a new, reliable, high-quality source of water to recharge the Orange County Groundwater Basin (see Case Study 2.7.15).

2.6.4 Direct Potable Water Reuse

Direct potable reuse is currently practiced in only one city in the world, Windhoek, Namibia. This city uses direct potable reuse on an intermittent basis only. In the U.S., the most extensive research focusing on direct potable reuse has been conducted in Denver, Colorado; Tampa, Florida; and San Diego, California. A considerable investment in potable reuse research has been made in Denver, Colorado, over a period of more than 20 years. This research included operation of a 1-mgd (44-l/s) reclamation plant in many different process modes over a period of about 10 years (Lauer, 1991). The product water was reported to be of better quality than many potable water sources in the region. The San Diego Total Resource Recovery Project was executed to demonstrate the feasibility of using natural systems for secondary treatment with subsequent advanced wastewater treatment to provide a water supply equivalent or better than the quality of imported water supplied to the region (WEF/AWWA, 1988). **Tables 2-11** and **2-12** show the advanced wastewater treatment effluent concentrations of minerals, metals, and trace organics for the San Diego Project.

Microbial analysis performed over a 2.5-year period, showed that water quality of advanced wastewater treatment effluent was low in infectious agents. Specifically, research showed:

- Spiking studies were conducted to determine the removal level of viruses. Results of 4 runs showed an overall virus removal rate through the primary, secondary, and advanced wastewater treatment plants of between 99.999 9 percent and 99.999 99 percent. Levels of removal were influenced by the number of viruses introduced. Viruses were not detected in more than 20.2×10^4 l of sample.

- Enteric bacterial pathogens (that is, *Salmonella*, *Shigella*, and *Campylobacter*) were not detected in 51 samples of advanced wastewater treatment effluent.

- Protozoa and metazoa of various types were absent

3.1.1 Preliminary Investigations

This is a fact-finding phase, meant to rough out physical, economic, and legal/institutional issues related to water reuse planning. The primary task is to locate all potential sources of effluent for reclamation and reuse and all potential markets for reclaimed water. It is also important to identify institutional constraints and enabling powers that might affect reuse. This phase should be approached with a broad view. Exploration of all possible options at this early planning stage will establish a practical context for the plan and also help to avoid creating dead-ends in the planning process.

Questions to be addressed in this phase include:

- What local sources of effluent might be suitable for reuse?
- What are the potential local markets for reclaimed water?
- What other nontraditional freshwater supplies are available for reuse?
- What are the present and projected reliability benefits of fresh water in the area?
- What are the present and projected user costs of fresh water in the area?
- What sources of funding might be available to support the reuse program?
- How would water reuse "integrate," or work in harmony with present uses of other water resources in the area?
- What public health considerations are associated with reuse, and how can these considerations be addressed?
- What are the potential environmental impacts of water reuse?
- What type of reuse system is likely to attract the public's interest and support?
- What existing or proposed laws and regulations affect reuse possibilities in the area?
- What local, state, or federal agencies must review and approve implementation of a reuse program?
- What are the legal liabilities of a purveyor or user of reclaimed water?

The major task of this phase involves conducting a preliminary market assessment to identify potential reclaimed water users. This calls for defining the water market through discussions with water wholesalers and retailers, and by identifying major water users in the market. The most common tools used to gather this type of information are telephone contacts and/or letters to potential reuse customers. Often, a follow-up phone contact is needed in order to determine what portion of total water use might be satisfied by reclaimed water, what quality of water is required for each type of use, and how the use of reclaimed water might affect the user's operations or discharge requirements.

This early planning stage is an ideal time to begin to develop or reinforce strong working relationships, among wastewater managers, water supply agencies, and potential reclaimed water users. These working relationships will help to develop solutions that best meet a particular community's needs.

Potential users will be concerned with the quality of reclaimed water and reliability of its delivery. They will also want to understand state and local regulations that apply to the use of reclaimed water. Potential customers will also want to know about constraints to using reclaimed water. They may have questions about connection costs or additional wastewater treatment costs that might affect their ability to use the product.

3.1.2 Screening of Potential Markets

The essence of this phase is to compare the unit costs of fresh water to a given market and the unit costs of reclaimed water to that same market. On the basis of information gathered in preliminary investigations, one or more "intuitive projects" may be developed that are clear possibilities, or that just "seem to make sense." For example, if a large water demand industry is located next to a wastewater treatment plant, there is a strong potential for reuse. The industry has a high demand for water, and costs to convey reclaimed water would be low. Typically, the cost-effectiveness of providing reclaimed water to a given customer is a function of the customer's potential demand versus the distance of the customer from the source of reclaimed water. In considering this approach, it should be noted that a concentration of smaller customers might represent a service area that would be as cost-effective to serve as a single large user. Once these anchor customers are identified, it is often beneficial to search for smaller customers located along the proposed path of the transmission system.

The value of reclaimed water – even to an "obvious" potential user will depend on the:

- Quality of water to be provided, as compared to the user's requirements
- Quantity of fresh water available and the ability to meet fluctuating demand
- Effects of laws that regulate reuse, and the attitudes of agencies responsible for enforcing applicable laws
- Present and projected future cost of fresh water to the user

These questions all involve detailed study, and it may not be cost-effective for public entities to apply the required analyses to every possible reuse scenario. A useful first step is to identify a wide range of candidate reuse systems that might be suitable in the area and to screen these alternatives. Then, only the most promising project candidates move forward with detailed evaluations.

In order to establish a comprehensive list of reuse possibilities, the following factors should be taken into account:

- Levels of treatment – if advanced wastewater treatment (AWT) is currently required prior to discharge of effluent, cost savings might be available if a market exists for secondary treated effluent.
- Project size – the scale of reuse can range from conveyance of reclaimed water to a single user up to the general distribution of reclaimed water for a variety of nonpotable uses.
- Conveyance network – different distribution routes will have different advantages, taking better advantage of existing rights-of-way, for example, or serving a greater number of users.

In addition to comparing the overall costs estimated for each alternative, several other criteria can be factored into the screening process. Technical feasibility may be used as one criterion, and the comparison of estimated unit costs of reclaimed water with unit costs of fresh water, as another. An even more complex screening process may include a comparison of weighted values for a variety of objective and subjective factors, such as:

- How much flexibility would each system offer for future expansion or change?
- How much fresh water use would be replaced by each system?
- How complicated would program implementation be, given the number of agencies that would be involved in each proposed system?
- To what degree would each system advance the "state-of-the-art" in reuse?
- What level of chemical or energy use would be associated with each system?
- How would each system impact land use in the area?

Review of user requirements could enable the list of potential markets to be reduced to a few selected markets for which reclaimed water could be of significant value. The Bay Area Regional Water Recycling Program (BARWRP) in San Francisco, California used a sophisticated screening and alternative analysis procedure. This included use of a regional GIS-based market assessment, a computer model to evaluate cost-effective methods for delivery, detailed evaluation criteria, and a spreadsheet-based evaluation decision methodology (Bailey *et al.*, 1998). The City of Tucson, Arizona, also used a GIS database to identify parcels such as golf courses, parks, and schools with a potential high demand for turf irrigation. In Cary, North Carolina, the parcel database was joined to the customer-billing database allowing large water users to be displayed on a GIS map. This process was a key element in identifying areas with high concentrations of dedicated irrigation meters on the potable water system (CDM, 1997). As part of an evaluation of water reclamation by the Clark County Sanitation District, Nevada, the alternatives analysis was extended beyond the traditional technical, financial, and regulatory considerations to include intangible criteria such as:

- Public acceptance including public education
- Sensitivity to neighbors
- Administrative agencies for the project
- Institutional arrangements to implement
- Impacts to existing developments as facilities are constructed

Source: Pai *et. al.*, 1996

3.1.3 Detailed Evaluation of Selected Markets

The evaluation steps contained in this phase represent the heart of the analyses necessary to shape a reuse program. At this point, a certain amount of useful data should be known including the present freshwater consumption and costs for selected potential users and a ranking of "most-likely" projects. In this phase, a more detailed look at conveyance routes and storage requirements for each selected system will help to refine preliminary cost estimates. Funding and benefit options can be compared, user costs developed, and a comparison made between the costs and benefits of fresh water versus reclaimed water for each selected system. The detailed evaluation will also look in more detail at the environmental, institutional, and social aspects of each project.

Questions that may need to be addressed as part of the detailed evaluation include:

- What are the specific water quality requirements of each user? What fluctuation can be tolerated?

- What is the daily and seasonal water use demand pattern for each potential user?

- Can fluctuations in demand best be met by pumping capacity or by using storage? Where would storage facilities best be located?

- If additional effluent treatment is required, who should own and operate the additional treatment facilities?

- What costs will the users in each system incur in connecting to the reclaimed water delivery system?

- Will industrial users in each system face increased treatment costs for their waste streams as a result of using reclaimed water? If so, is increased internal recycling likely, and how will this affect their water use?

- Will customers in the service area allow project costs to be spread over the entire service area?

- What interest do potential funding agencies have in supporting each type of reuse program being considered? What requirements would these agencies impose on a project eligible for funding?

- Will use of reclaimed water require agricultural users to make a change to their irrigation patterns or to provide better control of any irrigation discharges?

- What payback period is acceptable to users who must invest in additional facilities for onsite treatment, storage, or distribution of reclaimed water?

- What are the prospects of industrial source control measures in the area, and would institution of such measures reduce the additional treatment steps necessary to permit reuse?

- How "stable" are the potential users in each selected candidate reuse system? Are they likely to remain in their present locations? Are process changes being considered that might affect their ability to use reclaimed water?

Many of these questions can be answered only after further consultation with water supply agencies and prospective users. Both groups may seek more detailed information as well, including the preliminary findings made in the first 2 phases of effort. The City of Tampa set the following goals and objectives for their first residential reclaimed water project:

- Demonstrate customer demand for the water

- Demonstrate customer willingness to pay for the service

- Show that the project would pay for itself and not be subsidized by any utility customer not receiving reclaimed water

- Make subscription to the reclaimed water service voluntary

Source: Grosh *et. al.*, 2002

Detailed evaluations should lead to a preliminary assessment of technical feasibility and costs. Comparison among alternative reuse programs will be possible, as well as preliminary comparison between these programs and alternative water supplies, both existing and proposed. In this phase, economic comparisons, technical optimization steps, and environmental assessment activities leading to a conceptual plan for reuse might be accomplished by working in conjunction with appropriate consulting organizations.

3.2 Potential Uses of Reclaimed Water

Urban public water supplies are treated to satisfy the requirements for potable use. However, potable use (drinking, cooking, bathing, laundry, and dishwashing) represents only a fraction of the total daily residential use of treated potable water. The remainder may not require water of potable quality. In many cases, water used for nonpotable purposes, such as irrigation, may be drawn from the same ground or surface source as municipal supplies, creating an indirect demand on potable supplies. The *Guidelines* examine opportunities for substituting reclaimed water for potable water supplies where potable water quality is not required. Specific reuse opportunities include:

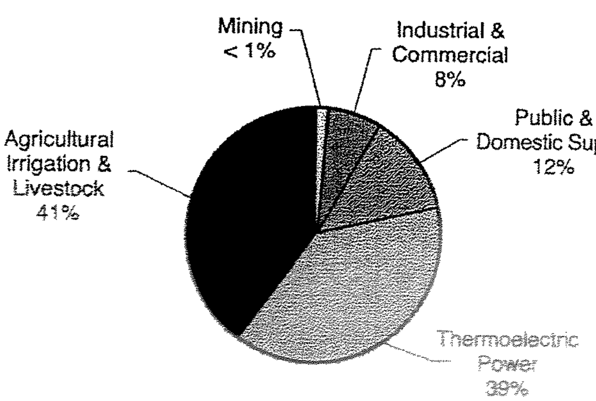
- Urban
- Industrial
- Agricultural
- Environmental and Recreational
- Groundwater Recharge
- Augmentation of Potable Supplies

The technical issues associated with the implementation of each of these reuse alternatives are discussed in detail in Chapter 2. The use of reclaimed water to provide both direct and indirect augmentation of potable supplies is also presented in Chapter 2.

3.2.1 National Water Use

Figure 3-2 presents the national pattern of water use in the U.S. according to the U.S. Geological Survey (Solley *et al.*, 1998). Total water use in 1995 was 402,000 mgd (152×10^7 m^3/d) with 341,000 mgd (129×10^7 m^3/d) being fresh water and 61,000 mgd (23×10^7 m^3/d) saline water. The largest freshwater demands were associated with agricultural irrigation/livestock and thermoelectric power, representing 41 and 39 percent, respectively, of the total freshwater use in the United States. Public and domestic water uses constitute 12 percent of the total demand.

Figure 3-2. 1995 U.S. Fresh Water Demands by Major Uses



Source: Solley *et. al.*, 1998

The remainder of the water use categories are mining and industrial/commercial with 8 percent of the demand. The 2 largest water use categories, thermoelectric power and agricultural irrigation, account for 80 percent of the total water use. These water uses present a great potential for supplementing with reclaimed water.

Figure 3-3 provides a flow chart illustrating the source, use, and disposition of fresh water in the U.S. Of the 341,000 mgd (129×10^7 m^3/d) of fresh water used in the U.S., only 29 percent is consumptively used and 71 percent is return flow. This amounts to a total of 241,000 mgd (91×10^7 m^3/d), of which 14 percent originates from domestic and commercial water use. Domestic wastewater comprises a large portion of this number.

Figure 3-4 shows estimated wastewater effluent produced daily in each state, representing the total potential reclaimed water supply from existing wastewater treatment facilities. **Figure 3-5** shows the estimated water demands by state in the United States. Estimated water demands are equal to the total fresh and saline withdrawals for all water-use categories (public supply, domestic, commercial, irrigation, livestock, industrial, mining, and thermoelectric power). Areas where high water demand exists might benefit by augmenting existing water supplies with reclaimed water. Municipalities in coastal and arid states, where water demands are high and freshwater supplies are limited, appear to have a reasonable supply of wastewater effluent that could, through proper treatment and reuse, greatly extend their water supplies.

Arid regions of the U.S. (such as the southwest) are candidates for wastewater reclamation, and significant reclamation projects are underway throughout this region. Yet, arid regions are not the only viable candidates for water reuse. Local opportunities may exist for a given municipality to benefit from reuse by extending local water supplies and/or reducing or eliminating surface water discharge. For example, the City of Atlanta, Georgia, located in the relatively water-rich southeast, has experienced water restrictions as a result of recurrent droughts. In south Florida, subtropical conditions and almost 55 inches (140 cm) per year of rainfall suggest an abundance of water; however, landscaping practices and regional hydrogeology combine to result in frequent water shortages and restrictions on water use. Thus, opportunities for water reclamation and reuse must be examined on a local level to judge their value and feasibility.

3.2.2 Potential Reclaimed Water Demands

Residential water demand can further be categorized as indoor use, which includes toilet flushing, cooking, laundry, bathing, dishwashing, and drinking; or outdoor use, of tourists, and seasons of high flow do not necessarily correspond with seasons of high irrigation demand. **Figure 3-9** illustrates the fluctuations in reclaimed water supply and irrigation demand in a southwest Florida community. Treatment facilities serving college campuses, resort areas, etc. also experience significant fluctuations in flow throughout the year. Where collection systems are prone to infiltration and inflow, significant fluctuations in flow may occur during the rainy season.

Information about flow quantities and fluctuations is critical in order to determine the size of storage facilities needed to balance supply and demand in water reuse systems. A more detailed discussion of seasonal storage requirements is provided in Section 3.5. Operational storage requirements to balance diurnal flow variations are detailed in Section 3.6.3.

3.3.2.4 Industrial Wastewater Contributions

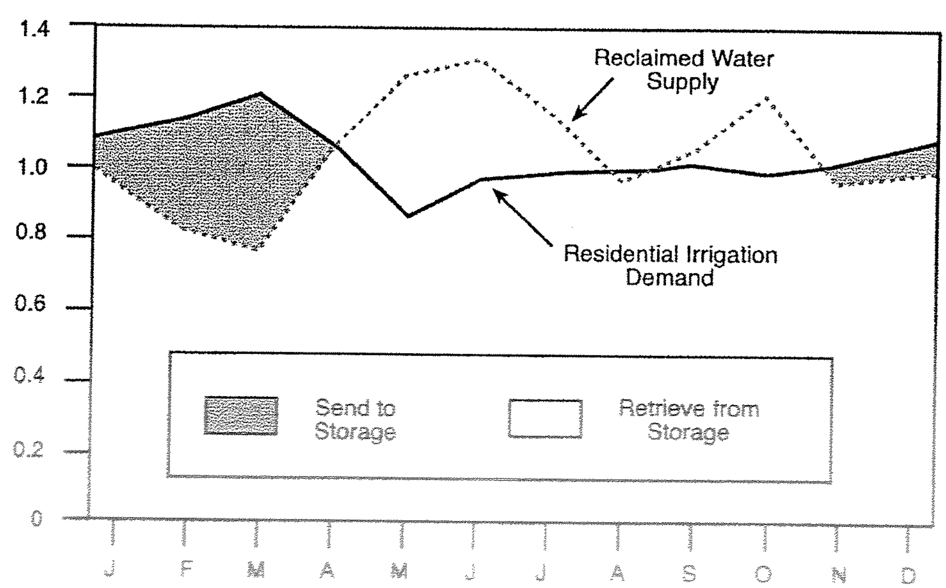
Industrial waste streams differ from domestic wastewater in that they may contain relatively high levels of elements and compounds, which may be toxic to plants and animals or may adversely impact treatment plant performance. Where industrial wastewater flow contributions to the WWTF are significant, reclaimed water quality may be affected. The degree of impact will, of course, depend on the nature of the industry. A rigorous pretreatment program is required for any water reclamation facility that receives industrial wastes to ensure the reliability of the biological treatment processes by excluding potentially toxic levels of pollutants from the sewer system. Planning a reuse system for a WWTF with substantial industrial flows will require identification of the constituents that may interfere with particular reuse applications, and appropriate monitoring for parameters of concern. Wastewater treatment facilities receiving substantial amounts of high-strength industrial wastes may be limited in the number and type of suitable reuse applications.

3.4 Treatment Requirements for Water Reuse

One of the most critical objectives in any reuse program is to ensure that public health protection is not compromised through the use of reclaimed water. To date there have not been any confirmed cases of infectious disease resulting from the use of properly treated reclaimed water in the U.S. Other objectives, such as preventing environmental degradation, avoiding public nuisance, and meeting user requirements, must also be satisfied, but the starting point remains the safe delivery and use of properly treated reclaimed water.

Protection of public health is achieved by: (1) reducing or eliminating concentrations of pathogenic bacteria, parasites, and enteric viruses in the reclaimed water, (2) controlling chemical constituents in reclaimed water, and/or (3) limiting public exposure (contact, inhalation, ingestion) to reclaimed water. Reclaimed water projects may vary significantly in the level of human exposure incurred, with a corresponding variation in the potential for health risks. Where human exposure is likely in a reuse application, reclaimed water should be treated to a high degree prior to its use. Conversely, where public access to

Figure 3-9. Reclaimed Water Supply vs. Irrigation Demand



a reuse site can be restricted so that exposure is unlikely, a lower level of treatment may be satisfactory, provided that worker safety is not compromised.

Determining the necessary treatment for the intended reuse application requires an understanding of the:

- Constituents of concern in wastewater
- Levels of treatment and processes applicable for reducing these constituents to levels that achieve the desired reclaimed water quality

3.4.1 Health Assessment of Water Reuse

The types and concentrations of pathogenic organisms found in raw wastewater are a reflection of the enteric organisms present in the customer base of the collection system. Chemical pollutants of concern may also be present in untreated wastewater. These chemicals may originate from any customer with access to the collection system, but are typically associated with industrial customers. Recent studies have shown that over-the-counter and prescription drugs are often found in wastewater.

The ability for waterborne organisms to cause disease is well established. Our knowledge of the hazards of chemical pollutants varies. In most cases, these concerns are based on the potential that adverse health effects may occur due to long-term exposure to relatively low concentrations. In addition, chemicals capable of mimicking hormones have been shown to disrupt the endocrine systems of aquatic animals.

In order to put these concerns into perspective with respect to water reclamation, it is important to consider the following questions.

- What is the intended use of the reclaimed water?

  Consideration should be given to the expected degree of human contact with the reclaimed water. It is reasonable to assume that reclaimed water used for the irrigation of non-food crops on a restricted agricultural site may be of lesser quality than water used for landscape irrigation at a public park or school, which in turn may be of a lesser quality than reclaimed water intended to augment potable supplies.

- Given the intended use of reclaimed water, what concentrations of microbiological organisms and chemicals of concern are acceptable?

  Reclaimed water quality standards have evolved over a long period of time, based on both scientific studies and practical experience. Chapter 4 provides a summary of state requirements for different types of reuse projects. While requirements might be similar from state to state, allowable concentrations and the constituents monitored are state-specific. Chapter 4 also provides suggested guidelines for reclaimed water quality as a function of use.

- Which treatment processes are needed to achieve the required reclaimed water quality?

  While it must be acknowledged that raw wastewater may pose a significant risk to public health, it is equally important to point out that current treatment technologies allow water to be treated to almost any quality desired. For many uses of reclaimed water, appropriate water quality can be achieved through conventional, widely practiced treatment processes. Advanced treatment beyond secondary treatment may be required as the level of human contact increases.

- Which sampling/monitoring protocols are required to ensure that water quality objectives are being met?

  As with any process, wastewater reuse programs must be monitored to confirm that they are operating as expected. Once a unit process is selected, there are typically standard Quality Assurance/Quality Control (QA/QC) practices to assure that the system is functioning as designed. Reuse projects will often require additional monitoring to prevent the discharge of substandard water to the reclamation system. On-line, real-time water quality monitoring is typically used for this purpose.

3.4.1.1 Mechanism of Disease Transmission

For the purposes of this discussion, the definition of disease is limited to illness caused by microorganisms. Health issues associated with chemical constituents in reclaimed water are discussed in Section 3.4.1.7. Diseases associated with microorganisms can be transmitted by water to humans either directly by ingestion, inhalation, or skin contact of infectious agents, or indirectly by contact with objects or individuals previously contaminated. The following circumstances must occur for an individual to become infected through exposure to reclaimed water: (a) the infectious agent must be present in the community and, hence, in the wastewater from that community; (b) the agents must survive, to a significant degree, all of the wastewater treatment processes to which they are exposed; (c) the individual must either directly or indirectly come into contact with the reclaimed water; and (d) the agents must be present in sufficient numbers to cause infection at the time of contact.

The primary means of ensuring reclaimed water can be used for beneficial purposes is first to provide the appropriate treatment to reduce or eliminate pathogens. Treatment processes typically employed in water reclamation systems are discussed below and in Section 3.4.2. Additional safeguards are provided by reducing the level of contact with reclaimed water. Section 3.6 discusses a variety of cross-connection control measures that typically accompany reuse systems.

The large variety of pathogenic microorganisms that may be present in raw domestic wastewater is derived principally from the feces of infected humans and primarily transmitted by consumption. Thus, the main transmission route is referred to as the "fecal-oral" route. Contaminated water is an important conduit for fecal-oral transmission to humans and occurs either by direct consumption or by the use of contaminated water in agriculture and food processing. There are occasions when host infections cause passage of pathogens in urine. The 3 principal infections leading to significant appearance of pathogens in urine are: urinary schistosomiasis, typhoid fever, and leptospirosis. Coliform and other bacteria may be numerous in urine during urinary tract infections. Since the incidence of these diseases in the U.S. is very low, they constitute little public health risk in water reuse. Microbial agents resulting from venereal infections can also be present in urine, but they are so vulnerable to conditions outside the body that wastewater is not a predominant vehicle of transmission (Feachem *et al.*, 1983 and Riggs, 1989).

3.4.1.2 Pathogenic Microorganisms and Health Risks

The potential transmission of infectious disease by pathogenic agents is the most common concern associated with reuse of treated municipal wastewater. Fortunately, sanitary engineering and preventive medical practices have combined to reach a point where waterborne disease outbreaks of epidemic proportions have, to a great extent, been controlled. However, the potential for disease transmission through water has not been eliminated. With few exceptions, the disease organisms of epidemic history are still present in today's sewage. The level of treatment today is more related to severing the transmission chain than to fully eradicating the disease agents.

Many infectious disease microbes affecting individuals in a community can find their way into municipal sewage. Most of the organisms found in untreated wastewater are known as enteric organisms; they inhabit the intestinal tract where they can cause disease, such as diarrhea. **Table 3-2** lists many of the infectious agents potentially present in raw domestic wastewater. These microbes can be classified into 3 broad groups: bacteria, parasites (parasitic protozoa and helminths), and viruses. Table 3-2 also lists the diseases associated with each organism.

a. Bacteria

Bacteria are microscopic organisms ranging from approximately 0.2 to 10 µm in length. They are distributed ubiquitously in nature and have a wide variety of nutritional requirements. Many types of harmless bacteria colonize in the human intestinal tract and are routinely shed in the feces. Pathogenic bacteria are also present in the feces of infected individuals. Therefore, municipal wastewater can contain a wide variety and concentration range of bacteria, including those pathogenic to humans. The numbers and types of these agents are a function of their prevalence in the animal and human community from which the wastewater is derived. Three of the more common bacterial pathogens found in raw wastewater are *Salmonella* sp, *Shigella* sp. and enteropathogenic *Escherichia coli* which have caused drinking water outbreaks with significant numbers of cases of hemolytic uremic syndrome (HUS) and multiple deaths (e.g. Walkerton, Ontario; Washington County, NY; Cabool, MO; Alpine, WY).

Bacterial levels in wastewater can be significantly lowered through either a "removal" or an "inactivation" process. The removal process involves the physical separation of the bacteria from the wastewater through sedimentation and/or filtration. Due to density considerations, bacteria do not settle as individual cells or even colonies. Typically, bacteria can adsorb to particulate matter or floc particles. These particles settle during sedimentation, secondary clarification, or during an advanced treatment process such as coagulation/flocculation/sedimentation using a coagulant. Bacteria can also be removed by using a filtration process that includes sand filters, disk (cloth) filters, or membrane processes. Filtration efficiency for a sand or cloth filter is dependent upon the effective pore size of the filtering medium and the presence of a "pre-coat" layer, usually other particulate matter. Because the pore sizes inherent to microfiltration and ultrafiltration membranes (including those membranes used in membrane bioreactors), bacteria are, to a large extent, completely removed due to size exclusion. Ultimately, the sedimented or filtered bacteria are removed from the overall treatment system through the sludge and backwash treatment system.

Table 3-2. Infectious Agents Potentially Present in Untreated Domestic Wastewater

Pathogen	Disease
Bacteria	
Shigella (spp.)	Shigellosis (bacillary dysentery)
Salmonella typhi	Typhoid fever
Salmonella (1700 serotypes spp.)	Salmonellosis
Vibro cholerae	Cholera
Escherichia coli (enteropathogenic)	Gastroenteritis and septicemia, hemolytic uremic syndrome (HUS)
Yersinia enterocolitica	Yersiniosis
Leptospira (spp.)	Leptospirosis
Campylobacter jejune	Gastroenteritis, reactive arthritis
Protozoa	
Entamoeba histolytica	Amebiasis (amebic dysentery)
Giardia lamblia	Giardiasis (gastroenteritis)
Cryptosporidium	Cryptosporidiosis, diarrhea, fever
Microsporidia	Diarrhea
Helminths	
Ascaris lumbricoides	Ascariasis (roundworm infection)
Ancylostoma (spp)	Ancylostomiasis (hookworm infection)
Necator americanus	Necatoriasis (roundworm infection)
Ancylostoma (spp.)	Cutaneous larva migrams (hookworm infection)
Strongloides stercoralis	Strongyloidiasis (threadworm infection)
Trichuris trichiura	Trichuriasis (whipworm infection)
Taenia (spp.)	Taeniasis (tapeworm infection)
Enterobius vermicularis	Enterobiasis (pinwork infection)
Echinococcus granulosus (spp.)	Hydatidosis (tapeworm infection)
Viruses	
Enteroviruses (polio, echo, coxsackie, new enteroviruses, serotype 68 to 71)	Gastroenteritis, heart anomolies, meningitis, others
Hepatitis A and E virus	Infectious hepatitis
Adenovirus	Respiratory disease, eye infections, gastroenteritis (serotype 40 and 41)
Rotavirus	Gastroenteritis
Parvovirus	Gastroenteritis
Noroviruses	Diarrhea, vomiting, fever
Astrovirus	Gastroenteritis
Calicivirus	Gastroenteritis
Coronavirus	Gastroenteritis

Source: Adapted from National Research Council, 1996; Sagik *et. al.*, 1978; and Hurst *et. al.*, 1989

Inactivation of bacteria refers to the destruction (death) of bacteria cells or the interference with reproductive ability using a chemical or energy agent. Such inactivation is usually referred to as disinfection. The most common disinfectants used in wastewater treatment are free chlorine, chloramines, ultraviolet (UV) light, and ozone. Chlorine, a powerful chemical oxidant, generally inactivates bacterial cells by causing physiological damage to cell membranes and damage to the internal cell components. Chloramines, chlorine substituted ammonia compounds, generally inactivate bacteria cells by disrupting DNA, thus causing direct cell death and/or inhibiting ability to reproduce. UV light also inactivates bacteria by damaging the DNA, thus inhibiting the ability to reproduce. Ozone, another powerful oxidant, can cause cell inactivation by direct damage to the cell wall and membrane, disruption of enzymatic reaction, and damage to DNA. The relative effectiveness of each chemical disinfectant is generally related to the product of disinfectant concentration and the disinfectant contact time. This product is commonly referenced as the "Ct" value. Tables of various Ct values required to inactivate bacteria (and other pathogens, such as viruses and protozoans) are readily available in the literature for clean (filtered) water applications. These Ct values are a function of temperature, pH, and the desired level of inactivation.

In recognition of the many constraints associated with analyzing wastewater for all of the potential pathogens that may be present, it has been common practice to use a microbial indicator or surrogate to indicate fecal contamination of water. Some bacteria of the coliform group have long been considered the prime indicators of fecal contamination and are the most frequently applied indicators used by state regulatory agencies to monitor water quality. The coliform group is composed of a number of bacteria that have common metabolic attributes. The total coliform groups are all gram-negative aspogenous rods, and most are found in feces of warm-blooded animals and in soil. Fecal coliforms are, for the most part, bacteria restricted to the intestinal tract of warm-blooded animals and comprise a portion of the total coliform group. Coliform organisms are used as indicators because they occur naturally in the feces of warm-blooded animals in higher concentrations than pathogens, are easily detectable, exhibit a positive correlation with fecal contamination, and generally respond similarly to environmental conditions and treatment processes as many bacterial pathogens. Where low levels of coliform organisms are used to indicate the absence of pathogenic bacteria, there is consensus among microbiologists that the total coliform analysis is not superior to the fecal coliform analysis. Specific methods have been developed to detect and enumerate *Escherichia coli* for use as a potential indicator organism.

b. Parasitic Protozoa and Helminths

The most common parasites in domestic untreated wastewater include several genera in the microspora, protozoa, trematode, and nematode families. Since the parasites cannot multiply in the environment, they require a host to reproduce and are excreted in the feces as spores, cysts, oocysts, or eggs, which are robust and resistant to environmental stresses such as dessication, heat, and sunlight. Most parasite spores, cysts, oocysts, and eggs are larger than bacteria and range in size from 1 μm to over 60 μm. While these parasites can be present in the feces of infected individuals who exhibit disease symptoms, carriers with unapparent infections can also excrete them, as may be the case with bacteria and viral infections as well. Furthermore, some protozoa such as *Toxoplasma* and *Cryptosporidium* are among the most common opportunistic infections in patients with acquired immunodeficiency syndrome (AIDS) (Slifko *et al.*, 2000).

There are several helminthic parasites that occur in wastewater. Examples include the roundworm *Ascaris* as well as other nematodes such as the hookworms and pinworm. Many of the helminths have complex life cycles, including a required stage in intermediate hosts. The infective stage of some helminths is either the adult organism or larvae, while the eggs or ova of other helminths constitute the infective stage of the organisms. The eggs and larvae, which range in size from about 10 μm to more than 100 μm, are resistant to environmental stresses and may survive usual wastewater disinfection procedures. Helminth ova are readily removed by commonly used wastewater treatment processes such as sedimentation, filtration, or stabilization ponds. A 1992 study in St. Petersburg, Florida, showed helminths were completely removed in the secondary clarifiers (Rose and Carnahan, 1992).

In recent years, the protozoan parasites have emerged as a significant human health threat in regards to chlorinated drinking water. In particular, the protozoa such as *Giardia lamblia*, *Cryptosporidium pavum*, and *Cyclospora cayetanensis* have caused numerous waterborne and/or foodborne outbreaks. *Microsporidia* spp. have also been implicated as a waterborne pathogen (Cotte *et al.*, 1999).

Protozoan pathogens can be reduced in wastewater by the same previously described mechanisms of removal and inactivation. *Cryptosporidium* oocysts are 4 to 6 mm in diameter while *Giardia* cysts range between 8 to 16 mm in diameter. Due to the relatively large size compared to bacteria, the protozoa can be removed by properly designed and operated sedimentation and filtration systems commonly employed in wastewater and water treatment. In terms of inactivation, commonly used disinfectants such as chlorine are not as effective for inactivating the protozoa as compared to bacteria and viruses. **Table 3-3** shows the relative microbial resistance to disinfection compared to *E. coli.* For the chemical disinfectants, a higher Ct value is required to show an equal level of inactivation as compared to bacteria. Advanced disinfection using irradiation such as UV or electron beam treatments have been shown to be effective for inactivating the pathogens with the necessary fluence or dose being roughly equivalent to that required by some bacteria.

c. Viruses

Viruses are obligate intracellular parasites able to multiply only within a host cell and are host-specific. Viruses occur in various shapes and range in size from 0.01 to 0.3 μm in cross-section and are composed of a nucleic acid core surrounded by an outer coat of protein. Bacteriophage are viruses that infect bacteria as the host; they have not been implicated in human infections and are often used as indicators in seeded virus studies. Coliphages are host specific viruses that infect the coliform bacteria.

Enteric viruses multiply in the intestinal tract and are released in the fecal matter of infected persons. Not all types of enteric viruses have been determined to cause waterborne disease, but over 100 different enteric viruses are capable of producing infections or disease. In general, viruses are more resistant to environmental stresses than many of the bacteria, although some viruses persist for only a short time in wastewater. The Enteroviruses, Rotavirus, and the Enteric Adenoviruses, which are known to cause respiratory illness, gastroenteritis, and eye infections, have been isolated from wastewater. Of the viruses that cause diarrheal disease, only the Noroviruss and Rotavirus have been shown to be major waterborne pathogens (Rose, 1986) capable of causing large outbreaks of disease.

There is no evidence that the Human Immunodeficiency Virus (HIV), the pathogen that causes AIDS, can be transmitted via a waterborne route (Riggs, 1989). The results of one laboratory study (Casson *et al.*, 1992), where primary and undisinfected secondary effluent samples were inoculated with HIV (Strain IIIB) and held for up to 48 hours at 25° C (77° F), indicated that HIV survival was significantly less than Polio virus survival under similar conditions. A similar study by Casson *et al.* in 1997 indicated that untreated wastewater spiked with blood cells infected with the HIV exhibited a rapid loss of HIV, although a small fraction remained stable for 48 hours.

Similar to bacteria and protozoan parasites, viruses can be both physically removed from the wastewater or inactivated. However, due to the relatively small size of typical viruses, the sedimentation and filtration processes are less effective at removal. Significant virus removal can be achieved with ultrafiltration membranes, possibly in the 3- to 4-log range. However, for viruses, inactivation is generally considered the more important of the 2 main reduction methods. Due to the size and relatively noncomplex nature of viruses, most disinfectants demonstrate reasonable inactivation levels at relatively low Ct values. Interestingly, for UV light disinfection, relatively high fluence values are required to inactivate viruses when compared to bacteria and protozoans. It is believed that the protein coat of the virus shields the ribonucleic acid (RNA) from UV light.

3.4.1.3 Presence and Survival of Pathogens

a. Presence

Bacteria, viruses, and parasites can all be detected in wastewater. Studies of pathogens have reported average levels of 6.2, 5.8, and 5.3 log cfu/100ml of *Yersinia, Shigella,* and *Salmonella* detected in primary-clarified sewage influent over a 2-year period in a U.S. facility (Hench *et al.*, 2003). *Salmonella* may be present in concentrations up to 10,000/l. The excretion of *Salmonella typhi* by asymptomatic carriers may vary from 5 x 10^3 to 45 x 10^6 bacteria/g of feces. But there are few studies in recent years, which have directly investigated the presence of bacterial pathogens and have focused more often on the indicator bacteria. Concentrations excreted by infected individuals range from 10^6 cysts, 10^7 oocysts and as high as 10^{12} virus particle per gram of feces for *Giardia*, *Cryptosporidium*, and *Rotavirus*, respectively (Gerba, 2000). Pathogen levels in wastewater can vary depending on infection in the community.

Levels of viruses, parasites, and indicator bacteria reported in untreated and secondary treated effluents are shown in **Tables 3-4** and **3-5**. These tables illustrate the tremendous range in the concentrations of microorgan-

Table 3-3. Ct Requirements for Free Chlorine and Chlorine Dioxide to Achieve 99 Percent Inactivation of *E. Coli* Compared to Other Microorganisms

Microbe	Cl_2 Ct	% Greater Cl_2 Ct Requirement Compared to *E. Coli*	Chloramine Ct	% Greater Chloramine Ct Requirement Compared to *E. Coli*
E. Coli	0.6	NA	113	NA
Poliovirus	1.7	96%	1,420	170%
Giardia	54-250	196-199%	430-580	117-135%
Cryptosporidium	>7,200	>200%	>7,200	>194%

Adapted from: Maier, 2000

isms that may be found in raw and secondary wastewater.

The methods currently used to detect *Cryptosporidium* oocysts and *Giardia* cysts are limited since they cannot assess viability or potential infectivity. Therefore, the health risks associated with finding oocysts and cysts in the environment cannot be accurately ascertained from occurrence data and the risks remain unknown.

Dowd *et al.* (1998) described a polymerase chain reaction (PCR) method to detect and identify the microsporidia (amplifying the small subunit ribosomal DNA of microsporidia). They found isolates in sewage, surface waters, and ground waters. The strain that was most often detected was *Enterocytozoon bieneusi*, which is a cause of diarrhea and excreted from infected individuals into wastewater. Microsporidia spores have been shown to be stable in the environment and remain infective for days to weeks outside their hosts (Shadduck, 1989; Waller, 1980; Shadduck and Polley, 1978). Because of their small size (1 to 5 μm), they may be difficult to remove using conventional filtration techniques. However, initial studies using cell culture suggest that the spores may be more susceptible to disinfection (Wolk *et al.*, 2000).

Under experimental conditions, absorption of viruses and *E. coli* through plant roots, and subsequent acropetal translocation has been reported (Murphy and Syverton, 1958). For example, one study inoculated soil with Polio virus, and found that the viruses were detected in the leaves of plants only when the plant roots were damaged or cut. The likelihood of translocation of pathogens through trees or vines to the edible portions of crops is extremely low, and the health risks are negligible.

Table 3-4. Microorganism Concentrations in Raw Wastewater

Organism	Range in Average Concentrations (CFU, PFU or Cysts/Oocysts)
Fecal Coliforms/100L	105 to 105
Enterococi/100L	10^4 to 10^5
Shigella /100mL	1 to 10^3
Salmonella /100mL	10^2 to 10^4
Helminth ova/100mL	1 to 10^3
Enteric virus/100L	1 to 5 $x10^3$
Giardia cysts/100L	0.39 to $4.9x10^4$
Cryptosporidium oocysts/100L	0.2 to 1.5 $x10^3$

Source: NRC, 1998 and Maier *et. al.*, 2000

Table 3-5. Microorganism Concentrations in Secondary Non-Disinfected Wastewater

Organism	Average Concentrations (CFU, PFU, or Cysts/Oocysts per 100L)
Fecal Coliforms	7,764
Enterococci	2,186
Enteric virus	20 to 650
Giardia cysts	5 to 2,297
Cryptosporidium oocysts	140

Source: NRC, 1998

b. Survival

Most pathogens do not increase in numbers outside of their host, although in some instances the ova of helminths do not mature to the larval stage until they are in the soil. In all cases, the numbers decrease at various rates, depending on a number of factors including the inherent biologic nature of the agent, temperature, pH, sunlight, relative humidity, and competing flora and fauna. Examples of relative survival times for some pathogens are given in **Table 3-6**. These values are intended to indicate relative survival rates only, and illustrate the various persistence of selected organisms.

3.4.1.4 Pathogens and Indicator Organisms in Reclaimed Water

There have been a number of studies regarding the presence of pathogens and indicator organisms in reclaimed water and such studies continue as experience in this field expands. Koivunen *et al.* (2003) compared the reduction of fecal coliforms to the reduction of *Salmonella* by conventional biological treatment, filtration, and disinfection. Fecal coliform bacteria were present at 1000-fold greater concentration, and the *Salmonella* bacteria were reduced to non-detectable levels by advanced treatment (greater than 99.9 percent). Fecal coliform bacteria were a good, conservative indicator of such reductions. However, given the numbers of *Salmonellae* in secondary effluents and the fact that 18 carried multiple antibiotic resistance, the authors concluded that without proper additional advanced treatment, there may be a significant public health risk.

A year-long study investigated a conventional reuse treatment facility in St. Petersburg, Florida (Rose *et al.*, 1996). In this facility, deep-bed sand filtration and disinfection, with total chlorine residual (4 to 5 mg/L) were the barriers assessed through both monitoring of naturally occurring bacteria, protozoa, and viruses, as well as through seeded challenge studies. Removals were 5 log for human vi-

Table 3-6. Typical Pathogen Survival Times at 20-30 °C

Pathogen	Survival Time (days)		
	Fresh Water & Sewage	Crops	Soil
Viruses[a]			
Enteroviruses[b]	<120 but usually <50	<60 but usually <15	<100 but usually <20
Bacteria			
Fecal coliforms[a,c]	<60 but usually <30	<30 but usually <15	<70 but usually <20
Salmonella spp.[a]	<60 but usually <30	<30 but usually <15	<70 but usually <20
Shigella spp.[a]	<30 but usually <10	<10 but usually <5	---
Vibrio cholerae[d]	<30 but usually <10	<5 but usually <2	<20 but usually <10
Protozoa			
Entamoeba histolytica cysts	<30 but usually <15	<10 but usually <2	<20 but usually <10
Helminths			
Ascaris lumbricoides eggs	Many months	<60 but usually <30	Many months

a In seawater, viral survival is less and bacterial survival is very much less, than in fresh water.
b Includes polio-, echo-, and coxsackieviruses
c Fecal coliform is not a pathogen but is often used as an indicator organism
d *V. cholerae* survival in aqueous environments is a subject of current uncertainty.

Source: Adapted from Feacham *et. al.*, 1983

ruses and coliphage indicators, with anywhere from 1.5 to 3 log reductions by disinfection. A 3 log reduction for protozoa was achieved and greater than 1 log reduction was achieved for bacteria and indicators. Protozoan viability was not evaluated. In this study, *Enterococci* and *Clostridium* were not included as alternative indicators. Only the phage was used as a virus indicator. Seeded trials using bacteriophage demonstrated a 1.5 and 1.6 log reduction by filtration and disinfection, respectively.

A second study was done at the Upper Occoquan Sewage Authority (UOSA) in Fairfax County, Virginia. Samples were collected once per month for 1 year from 8 sites from the advanced wastewater reclamation plant (Rose *et al.*, 2000). The 8 sites were monitored for indicator bacteria, total and fecal coliforms, enterococci, *Clostridium*, coliphage (viruses which infect *E.coli*), human enteric viruses, and enteric protozoa. Multimedia filtration reduced the bacteria by approximately 90 percent, but did not effectively reduce the coliphage or enteroviruses. The enteric protozoa were reduced by 85 to 95.7 percent. Chemical lime treatment was the most efficient barrier to the passage of microorganisms (reducing these microorganisms by approximately 99.99 percent for bacteria, 99.9 percent for *Clostridium* and enteroviruses, and 99 percent for protozoa). Disinfection was achieved through chlorination (free chlorine residuals of 0.2 to 0.5 mg/l), and effectively achieved another 90 to 99 percent reduction. Overall, the plant was able to achieve a 5 to 7 log reduction of bacteria, 5 log reduction of enteroviruses, 4 log reduction of *Clostridium*, and 3.5 log reduction of protozoa. Total coliforms, enterococci, *Clostridium*, coliphage, *Cryptosporidium*, and *Giardia* were detected in 4 or fewer samples of the final effluent. No enteroviruses or fecal coliforms were detected. Protozoa appeared to remain the most resistant microorganisms found in wastewater. However, as with the St. Petersburg study, protozoan viability in these studies was not addressed.

Table 3-7 provides a summary of influent and effluent microbiological quality for the St. Petersburg and Upper Occaquan studies for enterovirus, *Cryptosporidium*, and *Giardia*. Enteroviruses were found 100 percent of the time in untreated wastewater. The enteric protozoa, *Cryptosporidium*, and *Giardia* were found from 67 to 100 percent of the time in untreated wastewater. *Giardia* cysts were found to be more prevalent, and at higher concentrations than oocysts in wastewater, perhaps due to the increased incidence of infection in populations compared to cryptosporidiosis and higher asymptomatic infections. Levels of oocysts in sewage are similar throughout the world (Smith and Rose, 1998). However, crops irrigated with wastewater of a poorer quality in

Table 3-7 Pathogens in Untreated and Treated Wastewater

City	Organism	Untreated Wastewater		Reclaimed Water	
		% Positive	Average Value	% Positive	Average Value
St. Petersburg, FL	Enterovirus (PFU/100l)	100	1,033	8	0.01
	Cryptosporidium (oocysts/100l)	67	1,456	17	0.75
	Giardia (cysts/100l)	100	6,890	25	0.49
Upper Occoquan, VA	Enterovirus (PFU/100l)	100	1,100	0	0
	Cryptosporidium (oocysts/100l)	100	1,500	8.3	0.037
	Giardia (cysts/100l)	100	49,000	17	1.1

Source: Walker-Coleman *et. al.*, 2002; Rose and Carnahan, 1992; Sheikh and Cooper, 1998; Rose *et. al.*, 2001; Rose and Quintero-Betancourt, 2002; and York *et. al.*, 2002

Israel contained more oocysts than cysts (Armon *et al.*, 2002).

The results of these studies indicate that the treatment processes employed are capable of significantly reducing or eliminating these pathogens.

The State of Florida recognizes that *Giardia* and *Cryptosporidium* are pathogens of increasing importance to water reclamation and now requires monitoring for these pathogens (Florida DEP, 1999). Results of this monitoring are presented in **Table 3-8**. The Florida facilities highlighted in this table generally feature secondary treatment, filtration, and high-level disinfection. **Table 3-9** includes the associated data from these facilities for TSS, turbidity, and total chlorine residual.

Visual inspection studies in Florida and elsewhere routinely found *Giardia* cysts and *Cryptosporidium* oocysts in reclaimed water that received filtration and high-level disinfection and was deemed suitable for public access uses. A number of more detailed studies which considered the viability and infectivity of the cysts and oocysts suggested that *Giardia* was likely inactivated by chlorine but 15 to 40 percent of detected *Cryptosporidium* oocysts may survive (Keller, 2002; Sheikh, 1999; Garcia, 2002; Genacarro, 2003; Quintero, 2003). Other studies evaluating UV and the electron beam as alternatives to chlorine disinfection found that both parasites were easily inactivated (Mofidi 2002 and Slifko 2001). Both *Giardia* cysts and *Cryptosporidium* oocysts required less than 10mJ/cm^2 for complete inactivation by UV (Mofidi 2002 and Slifko 2001).

In December 2003, the Water Environment Research Foundation (WERF) initiated a series of workshops on indicators for pathogens in wastewater, stormwater, and biosolids. The first workshop considered the state of science for indicator organisms. Potential indicators for further study were identified in an attempt to improve upon current indicator organism use and requirements. The results of this effort are summarized in **Table 3-10**. Subsequent phases of this effort will evaluate the usefulness of the selected list of indicators and compare them with current indicators. Detailed studies will then be conducted using the most promising indicators in field studies at various sites in the U.S.

3.4.1.5 Aerosols

Aerosols are defined as particles less than 50 µm in diameter that are suspended in air. Viruses and most pathogenic bacteria are in the respirable size range; hence, the inhalation of aerosols is a possible direct mean of human infection. Aerosols are most often a concern where reclaimed water is applied to urban or agricultural sites with sprinkler irrigation systems, or where it is used for cooling water make-up.

The concentration of pathogens in aerosols is a function of their concentration in the applied water and the aerosolization efficiency of the spray process. During spray irrigation, the amount of water that is aerosolized can vary from less than 0.1 percent to almost 2 percent, with a mean aerosolization efficiency of 1 percent or less. Infection or disease may be contracted indirectly by deposited aerosols on surfaces such as food, vegetation, and clothes. The infective dose of some pathogens is lower for respiratory tract infections than for infections via the gastrointestinal tract. Therefore, for some pathogens, inhalation may be a more likely route for disease transmission than either contact or ingestion.

The infectivity of an inhaled aerosol depends on the depth of the respiratory penetration and the presence of pathogenic organisms capable of infecting the respiratory sys-

Table 3-8. Summary of Florida Pathogen Monitoring Data

Statistic	*Giardia*	*Cryptosporidium*
Number of observations	69	68
% having detectable concentrations	58%	22%
25 percentile (#/100 l)	ND	ND
50 percentile (#/100 l)	4	ND
75 percentile (#/100 l)	76	ND
90 percentile (#/100 l)	333	2.3
Maximum (#/100 l)	3,096	282

Notes: (a) All numeric data are total numbers of cysts or oocysts per 100 L.
(b) ND indicates a value less than detection.
Source: Walker-Coleman, *et. al.*, 2002.

Table 3-9. Operational Data for Florida Facilities

Statistic	TSS (mg/l)	Turbidity (NTU)	Chlorine Residual (mg/l)
Minimum	0.19	0.31	1.01
10 percentile	0.4	0.45	1.9
25 percentile	0.8	0.65	2.32
50 percentile	1	0.99	4.1
75 percentile	1.76	1.36	5
90 percentile	2.1	1.8	7.1
Maximum	6	4.5	10.67

Source: Walker-Coleman *et. al.*, 2002

tem. Aerosols in the 2 to 5 µm size range are generally excluded from the respiratory tract, with some that are subsequently swallowed. Thus, if gastrointestinal pathogens are present, infection could result. A considerably greater potential for infection occurs when respiratory pathogens are inhaled in aerosols smaller than 2 µm in size, which pass directly to the alveoli of the lungs (Sorber and Guter, 1975).

One of the most comprehensive aerosol studies, the Lubbock Infection Surveillance Study (Camann *et al.*, 1986), monitored viral and bacterial infections in a mostly rural community surrounding a spray injection site near Wilson, Texas. The source of the irrigation water was undisinfected trickling filter effluent from the Lubbock Southeast water reclamation plant. Spray irrigation of the wastewater significantly elevated air densities of fecal coliforms, fecal streptococci, mycobacteria, and coliphage above the ambient background levels for at least 650 feet (200 meters) downwind. The geometric mean concentration of enteroviruses recovered 150 to 200 feet (44 to 60 meters) downwind was 0.05 pfu/m^3, a level higher than that observed at other wastewater aerosol sites in the U.S. and in Israel (Camann *et al.*, 1988). While disease surveillance found no obvious connection between the self-reporting of acute illness and the degree of aerosol exposure, serological testing of blood samples indicated that the rate of viral infections was slightly higher among members of the study population who had a high degree of aerosol exposure (Camann *et al.*, 1986).

For intermittent spraying of disinfected reclaimed water, occasional inadvertent contact should pose little health hazard from inhalation. Cooling towers issue aerosols continuously, and may present a greater concern if the water is not properly disinfected. Although a great deal of effort has been expended to quantify the numbers of fecal coliforms and enteric pathogens in cooling tower waters, there is no evidence that they occur in large num-

Table 3-10 Some Suggested Alternative Indicators for Use in Monitoring Programs

Parameter	Pathogen Presence
Viruses	F+ RNA coliphages
	Somatic coliphages
	Adenovirus
	JC virus
Bacteria	*E. coli*
	Enterococci
	Bifidobacteria
Parasites	*Clostridium perfringens*
	Sulfite reducing
	Clostridium spp.
Non-microbial indicators	Fecal sterols
Pathogens as possible indicators	*Cryptosporidium*
	Giardia

Source: WERF Workshop, 2003

bers, although the numbers of other bacteria may be quite large (Adams and Lewis, n.d.).

No documented disease outbreaks have resulted from the spray irrigation of disinfected, reclaimed water. Studies indicate that the health risk associated with aerosols from spray irrigation sites using reclaimed water is low (U.S. EPA, 1980b). However, until more sensitive and definitive studies are conducted to fully evaluate the ability of pathogens contained in aerosols to cause disease, the general practice is to limit exposure to aerosols produced from reclaimed water that is not highly disinfected. Exposure is limited through design or operational controls. Design features include:

- Setback distances, which are sometimes called buffer zones
- Windbreaks, such as trees or walls around irrigated areas
- Low pressure irrigation systems and/or spray nozzles with large orifices to reduce the formation of fine mist
- Low-profile sprinklers
- Surface or subsurface methods of irrigation

Operational measures include:

- Spraying only during periods of low wind velocity
- Not spraying when wind is blowing toward sensitive areas subject to aerosol drift or windblown spray
- Irrigating at off-hours, when the public or employees would not be in areas subject to aerosols or spray

All these steps would be considered part of a best management plan for irrigation systems regardless of the source of water used.

Most states with reuse regulations or guidelines include setback distances from spray areas to property lines, buildings, and public access areas. Although predictive models have been developed to estimate microorganism concentrations in aerosols or larger water droplets resulting from spray irrigation, setback distances are determined by regulatory agencies in a somewhat arbitrary manner, using levels of disinfection, experience, and engineering judgment as the basis.

3.4.1.6 Infectious Disease Incidence Related to Wastewater Reuse

Epidemiological investigations have focused on wastewater-contaminated drinking water supplies, the use of raw or minimally-treated wastewater for food crop irrigation, health effects to farm workers who routinely contact poorly treated wastewater used for irrigation, and the health effects of aerosols or windblown spray emanating from spray irrigation sites using undisinfected wastewater. These investigations have all provided evidence of infectious disease transmission from such practices (Lund, 1980; Feachem *et al.*, 1983; Shuval *et al.*, 1986).

Review of the scientific literature, excluding the use of raw sewage or primary effluent on sewage farms in the late 19th century, does not indicate that there have been no confirmed cases of infectious disease resulting from reclaimed water use in the U.S. where such use has been in compliance with all appropriate regulatory controls. However, in developing countries, the irrigation of market crops with poorly treated wastewater is a major source of enteric disease (Shuval *et al.*, 1986).

Occurrences of low level or endemic waterborne diseases associated with exposure to reclaimed water have been difficult to ascertain for several reasons:

- Current detection methods have not been sufficiently sensitive or specific enough to accurately detect low concentrations of pathogens, such as viruses and protozoa, even in large volumes of water.
- Many infections are often not apparent, or go unreported, thus making it difficult to establish the endemicity of such infections.
- The apparently mild nature of many infections preclude reporting by the patient or the physician.
- Current epidemiological techniques are not sufficiently sensitive to detect low-level transmission of these diseases through water.
- Illness due to enteroviral or parasite infections may not become obvious for several months or years.
- Once introduced into a population, person-to-person contact can become a secondary mode of transmission of many pathogens, thereby obscuring the role of water in its transmission.

Because of the insensitivity of epidemiological studies to provide a direct empirical assessment of microbial health risk due to low-level exposure to pathogens, methodologies have increasingly relied on indirect measures of risk by using analytical models for estimation of the intensity of human exposure and the probability of human response from the exposure. Microbial risk assessment involves evaluating the likelihood that an adverse health effect may occur from human exposure to one or more potential pathogens. Most microbial risk assessments in the past have used a framework originally developed for chemicals that is defined by 4 major steps: (1) hazard identification, (2) dose-response identification, (3) exposure assessment, and (4) risk characterization. However, this framework does not explicitly acknowledge the differences between health effects due to chemical exposure versus those due to microbial exposure. Those differences include acute versus chronic health effects, potential for person-to-person transmission of disease, and the potential need to account for the epidemiological status of the population (Olivieri, 2002).

Microbial risk analyses require several assumptions to be made. These assumptions include a minimum infective dose of selected pathogens, concentration of pathogens present, quantity of pathogens ingested, inhaled, or otherwise contacted by humans, and probability of infection based on infectivity models. The use of microbial risk assessment models have been used extensively by the U.S. Department of Agriculture (USDA) to evaluate food safety for pathogens such as Listeria Monocytogenes in ready to eat foods (USDA, n.d.). The World Health Organization (WHO) and Food and Agriculture Organization (FAO) also provide risk assessment methodologies for use in evaluating food safety (Codex Alimentarius).

In order to assess health risks associated with the use of reclaimed water, pathogen risk assessment models to assess health risks associated with the use of reclaimed water have been used as a tool in assessing relative health risks from microorganisms in drinking water (Cooper *et al.*, 1986; Gerba and Haas, 1988; Olivieri *et al.*, 1986; Regli *et al.*, 1991; Rose *et al.*, 1991; Gale, 2002) and reclaimed water (Asano and Sakaji, 1990; EOA, Inc., 1995; Rose and Gerba, 1991; Tanaka *et al.*, 1998; Patterson *et al.*, 2001). Most of the models calculated the probability of individual infection or disease as a result of a single exposure. One of the more sophisticated models calculates a distribution of risk over the population by utilizing epidemiological data such as incubation period, immune status, duration of disease, rate of symptomatic development, and exposure data such as processes affecting pathogen concentration (EOA, Inc., 1995).

At the present time, no wastewater disinfection or reclaimed water standards or guidelines in the U.S. are based on risk assessment using microorganism infectivity models. Florida is investigating such an approach and has suggested levels of viruses between 0.04 to 14/100 l, depending on the virus (ranging from Rotavirus infectivity to a less infectious virus), viable oocysts at 22/100 l, and viable cysts at 5/100 l (York and Walker-Coleman, 1999). Microbial risk assessment methodology is a useful tool in assessing relative health risks associated with water reuse. Risk assessment will undoubtedly play a role in future criteria development as epidemiological-based models are improved and refined.

3.4.1.7 Chemical Constituents

The chemical constituents potentially present in municipal wastewater are a major concern when reclaimed water is used for potable reuse. These constituents may also affect the acceptability of reclaimed water for other uses, such as food crop irrigation or aquaculture. Potential mechanisms of food crop contamination include:

- Physical contamination, where evaporation and repeated applications may result in a buildup of contaminants on crops
- Uptake through the roots from the applied water or the soil, although available data indicate that potentially toxic organic pollutants do not enter edible portions of plants that are irrigated with treated municipal wastewater (National Research Council, 1996)
- Foliar uptake

With the exception of the possible inhalation of volatile organic compounds (VOCs) from indoor exposure, chemical concerns are less important where reclaimed water is not to be consumed. Chemical constituents are a consideration when reclaimed water percolates into groundwater as a result of irrigation, groundwater recharge, or other uses. These practices are covered in Chapter 2. Some of the inorganic and organic constituents in reclaimed water are listed in **Table 3-11**.

a. Inorganics

In general, the health hazards associated with the ingestion of inorganic constituents, either directly or through food, are well established (U.S. EPA, 1976). EPA has set maximum contaminant levels (MCLs) for drinking water. The concentrations of inorganic constituents in reclaimed water depend mainly on the source of wastewater and the degree of treatment. Residential use of water typically adds about 300 mg/l of dissolved inorganic solids, although the amount added can range from approximately 150 mg/l to more than 500 mg/l (Metcalf & Eddy, 2002). As indicated in Table 3-11 the presence of total dissolved solids, nitrogen, phosphorus, heavy metals, and other inorganic constituents may affect the acceptability of reclaimed water for different reuse applications. Wastewater treatment using existing technology can generally reduce many trace elements to below recommended maximum levels for irrigation and drinking water. Uses in wetlands and recreational surface waters must also consider aquatic life protection and wetland habitat.

b. Organics

The organic make-up of raw wastewater includes naturally occurring humic substances, fecal matter, kitchen wastes, liquid detergents, oils, grease, and other substances that, in one way or another, become part of the sewage stream. Industrial and residential wastes may contribute significant quantities of synthetic organic compounds.

The need to remove organic constituents is related to the end use of reclaimed water. Some of the adverse effects associated with organic substances include:

- Aesthetic effects – organics may be malodorous and impart color to the water
- Clogging – particulate matter may clog sprinkler heads or accumulate in soil and affect permeability
- Proliferation of microorganisms – organics provide food for microorganisms
- Oxygen consumption – upon decomposition, organic substances deplete the dissolved oxygen content in streams and lakes. This negatively impacts the aquatic life that depends on the oxygen supply for survival
- Use limitation – many industrial applications cannot tolerate water that is high in organic content
- Disinfection effects – organic matter can interfere with chlorine, ozone, and ultraviolet disinfection, thereby making them less available for disinfection purposes. Further, chlorination may result in formation of potentially harmful disinfection byproducts
- Health effects – ingestion of water containing certain organic compounds may result in acute or chronic health effects.

The wide range of anthropogenic organic contaminants in streams influenced by urbanization (including wastewater contamination) includes pharmaceuticals, hormones, antioxidants, plasticizers, solvents, polynuclear aromatic hydrocarbons (PAHs), detergents, pesticides, and their metabolites (Kolpin *et al.*, 2002). The stability and persistence of these compounds are extremely variable in the stream/sediment environment. A recent comprehensive study of the persistence of anthropogenic and natural organic molecules during groundwater recharge suggests that carbamezepine may survive long enough to serve as a useful tracer compound of wastewater origin (Clara *et al.*, 2004).

Table 3-11. **Inorganic and Organic Constituents of Concern in Water Reclamation and Reuse**

Constituent	Measured Parameters	Reasons for Concern
Suspended Solids	Suspended solids (SS), including volatile and fixed solids	Organic contaminants, heavy metals, etc. are absorbed on particulates. Suspended matter can shield microorganisms from disinfectants. Excessive amounts of suspended solids cause plugging in irrigation systems.
Biodegradable Organics	Biochemical oxygen demand, chemical oxygen demand, total organic carbon	Aesthetic and nuisance problems. Organics provide food for microorganisms, adversely affect disinfection processes, make water unsuitable for some industrial or other uses, consume oxygen, and may result in acute or chronic effects if reclaimed water is u
Nutrients	Nitrogen, Phosphorus, Potassium	Nitrogen, phosphorus, and potassium are essential nutrients for plant growth and their presence normally enhances the value of the water for irrigation. When discharged to the aquatic environment, nitrogen and phosphorus can lead to the growth of undesir
Stable Organics	Specific compounds (e.g., pesticides, chlorinated hydrocarbons)	Some of these organics tend to resist conventional methods of wastewater treatment. Some organic compounds are toxic in the environment, and their presence may limit the suitability of reclaimed water for irrigation or other uses. Chlorine reacts with man
Hydrogen Ion Concentration	pH	The pH of wastewater affects disinfection, coagulation, metal solubility, as well as alkalinity of soils. Normal range in municipal wastewater is pH = 6.5 - 8.5, but industrial waste can alter pH significantly.
Heavy Metals	Specific elements (e.g., Cd, Zn, Ni, and Hg)	Some heavy metals accumulate in the environment and are toxic to plants and animals. Their presence may limit the suitability of the reclaimed water for irrigation or other uses.
Dissolved Inorganics	Total dissolved solids, electrical Conductivity, specific elements (e.g., Na, Ca, Mg, Cl, and B)	Excessive salinity may damage some crops. Specific inorganics electrical conductivity ions such as chloride, sodium, and boron are toxic to specific elements (e.g., in some crops, sodium may pose soil permeability Na, Ca, Mg, Cl, and B problems).
Residual Chlorine	Free and combined chlorine	Excessive amounts of free available chlorine (>0.05 Chlorine chlorine mg/l) may cause leaf-tip burn and damage some sensitive crops. However, most chlorine in reclaimed water is in a combined form, which does not cause crop damage. Some concerns are expre

Source: Adapted from Pettygrove and Asano, 1985

The health effects resulting from organic constituents are of primary concern for indirect or direct potable reuse. In addition, these constituents may be of concern where reclaimed water is utilized for food crop irrigation, where reclaimed water from irrigation or other beneficial uses reaches potable groundwater supplies, or where the organics may bioaccumulate in the food chain (e.g., in fish-rearing ponds).

Traditional measures of organic matter such as BOD, chemical oxygen demand (COD), and total organic carbon (TOC), are widely used as indicators of treatment efficiency and water quality for many nonpotable uses of reclaimed water. However, these measures have only indirect relevance related to evaluating toxicity and health effects. Sophisticated analytical instrumentation makes it possible to identify and quantify extremely low levels of organic constituents in water. Examples include gas chromatography/tandem mass spectrometry (GC/MS/MS) or high performance liquid chromatography/mass spectrometry (HPLC/MS). These analyses are costly and may require extensive and difficult sample preparation, particularly for nonvolatile organics.

Organic compounds in wastewater can be transformed into chlorinated organic species where chlorine is used for disinfection purposes. In the past, most attention was focused on the trihalomethane (THM) compounds; a family of organic compounds typically occurring as chlorine or bromine-substituted forms of methane. Chloroform, a commonly found THM compound, has been implicated in the development of cancer of the liver and kidney. Improved analytical capabilities to detect extremely low levels of chemical constituents in water have resulted in identification of several health-significant chemicals and disinfection byproducts in recent years. For example, the extremely potent carcinogen, N-nitrosodimethylamine (NDMA) is present in sewage and is produced when municipal wastewater effluent is disinfected with chlorine or chloramines (Mitch *et al*, 2003). In some situations, the concentration of NDMA present in reclaimed water exceeds action levels set for the protection of human health, even after reverse osmosis treatment. To address concerns associated with NDMA and other trace organics in reclaimed water, several utilities in California have installed UV/H2O2 treatment systems for treatment of reverse osmosis permeate.

Quality standards have been established for many inorganic constituents. Treatment and analytical technology has demonstrated the capability to identify, quantify, and control these substances. Similarly, available technology is capable of eliminating pathogenic agents from contaminated waters. On the basis of available information, there is no indication that health risks from using highly treated reclaimed water for potable purposes are greater than those from using existing water supplies (National Research Council, 1994). Yet, unanswered questions remain about organic constituents, due mainly to their potentially large numbers and unresolved health risk potentials related to long-term, low-level exposure. Assessment of health risks associated with potable reuse is not definitive due to limited chemical and toxicological data and inherent limitations in available epidemiological and toxicological methods. The results of epidemiological studies directed at drinking water have generally been inconclusive, and extrapolation methodologies used in toxicological assessments provide uncertainties in overall risk characterization (National Research Council, 1998).

3.4.1.8 Endocrine Disrupters

In addition to the potential adverse effects of chemicals described in Section 3.4.1.6, certain chemical constituents present in wastewater also can disrupt hormonal systems. This phenomenon, which is referred to as endocrine disruption, can occur through a variety of mechanisms associated with hormone synthesis, hormone receptor binding, and hormone transformation. As a result of the many mechanisms through which chemicals can impact hormone function, a large number of chemicals are classified as endocrine disrupters. However, the exact types of chemicals that are classified as endocrine disrupters vary among researchers. **Table 3-12** highlights a number of example sources of potential endocrine disrupters.

For example, the oxyanion, perchlorate, is an endocrine disrupter because it affects the thyroid system (U.S. EPA, 2002). The herbicide, atrazine, is an endocrine disrupter because it affects an enzyme responsible for hormone regulation (Hayes *et al.* 2002). A USGS project recently sampled 139 streams in 30 states for any 1 of 95 endocrine disrupters. The results indicated that 80 percent of the streams had at least 1 of these compounds (McGovern and McDonald, 2003). The topic of endocrine disruption has significant implications for a wide variety of chemicals used by industry, agriculture, and consumers. As a result, the EPA, the European Union (EU), and other government organizations are currently evaluating approaches for regulating endocrine-disrupting chemicals.

With respect to water reuse, the greatest concerns associated with endocrine disruption are related to a series of field and laboratory studies demonstrating that chemicals in wastewater effluent caused male fish to exhibit female characteristics (Purdom *et al.*, 1994; Harries *et al.*, 1996; Harries *et al.*, 1997). This process, which is referred to as feminization, has been attributed mostly to the presence of steroid hormones excreted by humans

(Desbrow *et al.*, 1998 and Snyder *et al.*, 2001). The hormones involved in fish feminization include the endogenous (*i.e.*, produced within the body) hormone 17b-estradiol as well as hormones present in pharmaceuticals (*e.g.*, ethinyl estradiol in birth control pills). Other chemicals capable of feminizing fish are also present in wastewater. These include nonylphenol and alkylphenol polyethoxylates, both of which are metabolites of non-ionic detergents formed during secondary wastewater treatment (Ahel *et al.*, 1994).

The specific endocrine-disrupting chemicals in reclaimed water can be quantified using modern analytical methods. As indicated previously, the compounds most likely to be responsible for feminization of fish include steroid hormones (*e.g.*, 17b-estradiol and ethinyl estradiol) and detergents metabolites (*e.g.*, nonylphenol and alkylphenol polyethoxylates). Although these compounds cannot be quantified at the levels expected in reclaimed water with the gas chromatography/mass spectrometry (GC/MS) techniques routinely used to quantify priority pollutants, they can be measured with equipment available in many modern laboratories. For the hormones, analytical methods such as gas chromatography/tandem mass spectrometry (GC/MS/MS) (Ternes *et al.*, 1999, Huang and Sedlak, 2001), high performance liquid chromatography/mass spectrometry (HPLC/MS) (Ferguson *et al.*, 2001), or immunoassays (Huang and Sedlak, 2001 and Snyder *et al.*, 2001) are needed to detect the low concentrations present in wastewater effluent (*e.g.*, ethinyl estradiol concentrations are typically less than 2 υg/l in wastewater effluent). Although the endocrine-disrupting detergent metabolites are present at much higher concentrations than the hormones, their analysis also requires specialized analytical methods (Ahel *et al.*, 1994) not available from many commercial laboratories.

Bioassays can also be used to quantify the potential of reclaimed water to cause endocrine disruption. These methods are attractive because they have the potential to detect all of the difficult-to-measure endocrine-disrupting chemicals in 1 assay. The simplest bioassays involve *in vitro* tests, in which a hormone receptor from a mammalian cell is used to detect endocrine-disrupting chemicals. Among the different *in vitro* assays, the Yeast Estrogen Screen (YES) assay has been employed most frequently (Desbrow *et al.*, 1998). Comparisons between *in vitro* bioassays and chemical measurements yield

Table 3-12. Examples of the Types and Sources of Substances that have been Reported as Potential Endocrine-Disrupting Chemicals

Category	Examples of Substances	Examples of Uses	Examples of Sources
Polychlorinated Compounds	polychlorinated dioxins and polychlorinated biphenyls	industrial production of byproducts (mostly banned)	incineration and landfill runoff
Organochlorine Pesticides	DDT, dieldrin, and lindane	insecticides (many phased out)	agricultural runoff
Current Use Pesticides	atrazine, trifluralin, and permethrin	pesticides	agricultural runoff
Organotins	tributyltin	antifoulants on ships	harbors
Alkylphenolics	nonylphenol and octylphenol	surfactants (and their metabolites)	industrial and municipal effluents
Phthalates	dibutyl phthalate and butylbenzyl phthalate	plasticisers	industrial effluent
Sex Hormones	17-beta estradiol and estrone	produced naturally by animals	municipal effluents
Synthetic Steroids	ethinylestradiol	contraceptives	municipal effluents
Phytoestrogens	isoflavones, lignans, coumestans	present in plant material	pulp mill effluents

Source: Adapted from McGovern and McDonald, 2003 and Berkett and Lester, 2003 consistent results, indicating that steroid hormones are the most significant endocrine disrupting chemicals in wastewater effluent. Unfortunately, *in vitro* bioassays do not always detect compounds that disrupt hormone systems through mechanisms other than binding to hormone receptors. As a result, *in vivo* bioassays, usually performed with fish, may provide more accurate results. A clear dose-related response to various endocrine-disrupting compounds has been established in fish; however, little is known about species differences in sensitivity to exposure. Individual responses to exposure may also vary widely (Routledge *et al.*, 1998). Because many laboratories are unable to perform *in vivo* bioassays under the necessary conditions (*e.g.*, flow-through tests with rainbow trout), *in vivo* bioassays are not always practical. Available data suggest that nitrification/denitrification and filtration can reduce the concentrations of hormones and detergent metabolites while reverse osmosis lowers concentrations to levels that are unlikely to cause endocrine disruption (Huang and Sedlak, 2001 and Fujita *et al.*, 1996).

The current focus of research on disruption of the estrogen system may be attributable to the relative ease of detecting this form of endocrine disruption. As additional research is performed, other chemicals in wastewater effluent may be found to disrupt hormonal systems through mechanisms yet to be documented. For example, although results from *in vitro* bioassays suggest that the steroid hormones are most likely responsible for feminization of fish, it is possible that other endocrine disrupters contribute to the effect through mechanisms that cannot be detected by the bioassays.

The ecological implications associated with the feminization of fish are unknown. The potential of reclaimed water to cause endocrine disruption in humans is also unknown. It is anticipated that problems associated with endocrine disruption could occur, given prolonged consumption of substantial volumes of polluted water. The compounds in wastewater effluent that are believed to be responsible for feminization of fish may not pose a serious risk for humans because of differences between human and fish physiology. For example, the hormone 17b-estradiol is not used in the oral form in clinical applications because it would be metabolized before it could reach its target. Nevertheless, the evidence of endocrine disruption in wildlife and the absence of data about the effects of low-level exposure to endocrine disrupting compounds in humans has led to new scrutiny regarding endocrine-disrupting chemicals in reclaimed water.

3.4.2 Treatment Requirements

Untreated municipal wastewater may include contributions from domestic and industrial sources, infiltration and inflow from the collection system, and, in the case of combined sewer systems, urban stormwater runoff. The quantity and quality of wastewater derived from each source will vary among communities, depending on the number and type of commercial and industrial establishments in the area and the condition of the sewer system.

Levels of wastewater treatment are generally classified as preliminary, primary, secondary, and advanced. Advanced wastewater treatment, sometimes referred to as tertiary treatment, is generally defined as anything beyond secondary treatment. A generalized flow sheet for municipal wastewater treatment is shown in **Figure 3-10**.

In the last decade, significant advances were made in wastewater treatment equipment, design, and technology. For example, biological nutrient removal (BNR) processes have become more refined. Membranes are capable of producing higher quality effluent at higher flux rates and lower pressures than was possible before. Membrane bioreactors (MBRs) have shown to be effective in producing a high quality effluent, while greatly reducing a treatment plant's footprint. Microfiltration, used in some locations to replace conventional media filtration, has the advantage of effectively removing all parasite cysts (e.g., *Giardia* and *Cryptosporidium*). Advances in UV radiation technology have resulted in a cost competitive disinfection process capable of reducing the concentration of most pathogens to extremely low levels.

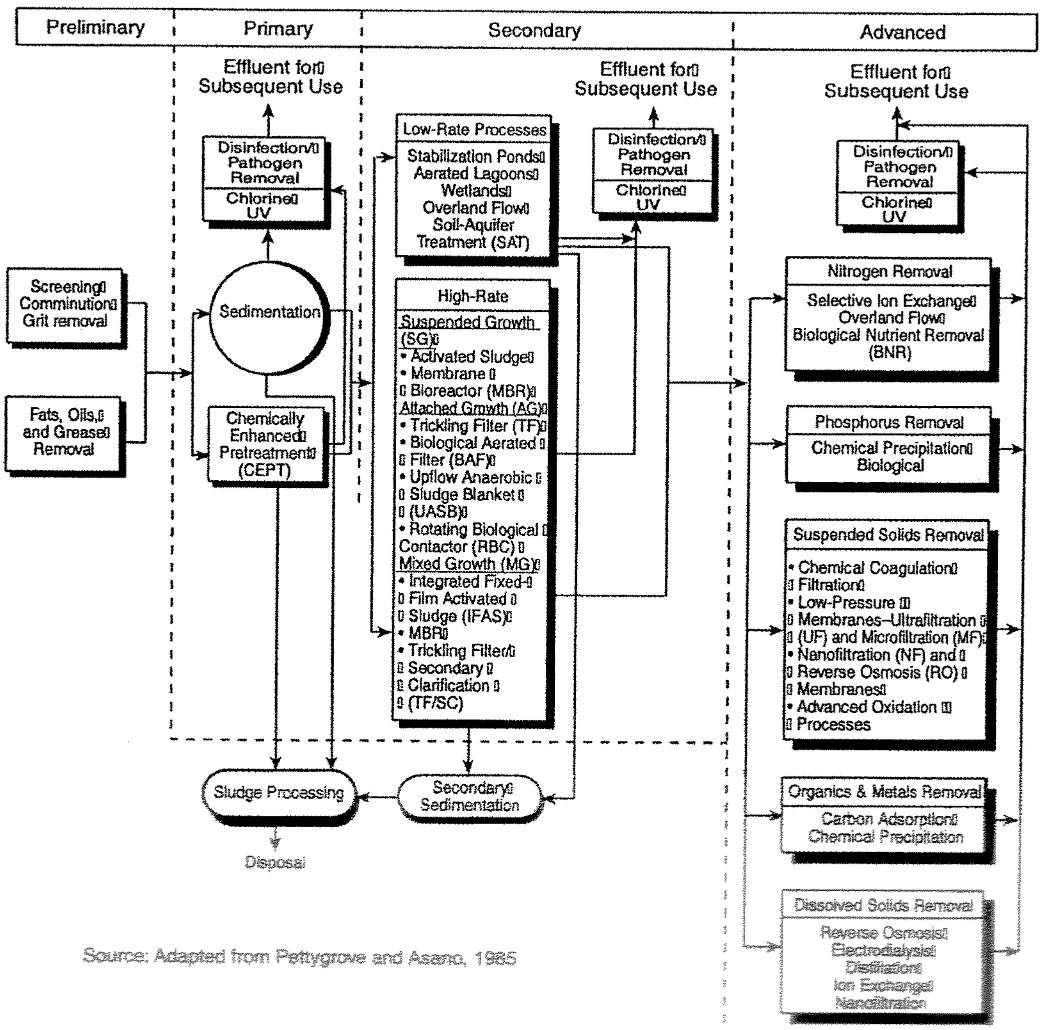
Wastewater treatment from raw to secondary is well understood and covered in great detail in other publications such as the Manual of Practice (MOP) 8, *Design of Municipal Wastewater Treatment Plants*, 4th Edition, (WEF, 1998). In this edition of the *Guidelines for Water Reuse* the discussion about treatment processes will be limited to those with a particular application to water reuse and reclamation. Such processes generally consist of disinfection and treatment beyond secondary treatment, although some limited access reuse programs may use secondary effluent without concern. It should be pointed out that treatment for particular pollutants at the water reclamation facility is not always the best answer. Source controls should also be investigated. In Orange County, California, 1,4-dioxane (listed as a probable human carcinogen based on animal studies) was found in 9 production wells at levels greater than the California action levels. This problem was solved by working with a treatment plant customer who voluntarily ceased discharge of 1,4-dioxane to the sewer system (Woodside and Wehner, 2002).

3.4.2.1 Disinfection

The most important process for the destruction of microorganisms is disinfection. In the U.S., the most common disinfectant for both water and wastewater is chlorine. Ozone and UV light are other prominent disinfectants used at wastewater treatment plants. Factors that should be considered when evaluating disinfection alternatives include disinfection effectiveness and reliability, capital costs, operating and maintenance costs, practicality (e.g., ease of transport and storage or onsite generation, ease of application and control, flexibility, complexity, and safety), and potential adverse effects. Examples of adverse effects include toxicity to aquatic life or formation of toxic or carcinogenic substances. The predominant advantages and disadvantages of disinfection alternatives are well known and have been summarized by the EPA in their Wastewater Technology Fact Sheets on Ultraviolet Disinfection (September 1999), Ozone Disinfection (September 1999), and Chlorine Disinfection (September 1999), Design Manual entitled, "Municipal Wastewater Disinfection" and Water Environment Federation (WEF) Manual of Practice FD-10 (1996).

The efficiency of chlorine disinfection depends on the water temperature, pH, degree of mixing, time of contact, presence of interfering substances, concentration and form of chlorinating species, and the nature and concentration of the organisms to be destroyed. In general, bacteria are less resistant to chlorine than viruses, which in turn, are less resistant than parasite ova and cysts.

Figure 3-10. Generalized Flow Sheet for Wastewater Treatment



Source: Adapted from Pettygrove and Asano, 1985

The chlorine dosage required to disinfect wastewater to any desired level is greatly influenced by the constituents present in the wastewater. Some of the interfering substances are:

- Organic constituents, which consume the disinfectant
- Particulate matter, which protects microorganisms from the action of the disinfectant
- Ammonia, which reacts with chlorine to form chloramines, a much less effective disinfectant species than free chlorine

In practice, the amount of chlorine added is determined empirically, based on desired residual and effluent quality. Chlorine, which in low concentrations is toxic to many aquatic organisms, is easily controlled in reclaimed water by dechlorination, typically with sulfur dioxide.

Chlorine is a regulated substance with a threshold quantity of 2,500 pounds (1130 kg). If a chlorine system contains a larger quantity of chlorine than the threshold quantity, a Risk Management Plan (RMP) must be completed. Two main factors of the RMP that prompt many municipalities to switch to alternative disinfection systems are: (1) the RMP is not a one-time requirement, it has to be updated every 5 years; and (2) concern over public reaction to the RMP, which requires that a "kill zone" be geographically defined around the treatment facility. This "kill zone" may include residential areas near the treatment plant. Thus, RMP requirements and decreasing chemical costs for commercial grade sodium hypochlorite have resulted in many municipalities switching from chlorine gas to commercial grade sodium hypochlorite to provide disinfection of their wastewater.

Ozone (O_3), is a powerful disinfecting agent and chemical oxidant in both inorganic and organic reactions. Due to the instability of ozone, it must be generated onsite from air or oxygen carrier gas. Ozone destroys bacteria and viruses by means of rapid oxidation of the protein mass, and disinfection is achieved in a matter of minutes. Ozone is a highly effective disinfectant for advanced wastewater treatment plant effluent, removing color, and contributing dissolved oxygen. Some disadvantages to using ozone for disinfection are: (1) the use of ozone is relatively expensive and energy intensive, (2) ozone systems are more complex to operate and maintain than chlorine systems, and (3) ozone does not maintain a residual in water.

UV is a physical disinfecting agent. Radiation at a wavelength of 254 mm penetrates the cell wall and is absorbed by the cellular nucleic acids. This can prevent replication by eliminating the organism's ability to cause infection. UV radiation is frequently used for wastewater treatment plants that discharge to surface waters to avoid the need for dechlorination prior to release of the effluent. UV is receiving increasing attention as a means of disinfecting reclaimed water for the following reasons: (1) UV may be less expensive than disinfecting with chlorine, (2) UV is safer to use than chlorine gas, (3) UV does not result in the formation of chlorinated hydrocarbons, and (4) UV is effective against *Cryptosporidium* and *Giardia*, while chlorine is not.

The effectiveness of UV radiation as a disinfectant (where fecal coliform limits are on the order of 200/100 ml) has been well established, and is used at small- to medium-sized wastewater treatment plants throughout the U.S. Today, UV radiation to achieve high-level disinfection for reuse operations is acceptable in some states. In recognition of the possible harmful effects of chlorine, the Florida Department of Environmental Protection (FDEP) encourages the use of alternative disinfection methods (FDEP, 1996). The WERF published a final report entitled, "Disinfection Comparison of UV Irradiation to Chlorination: Guidance for Achieving Optimal UV Performance." This report provides a broad-based discussion of the advantages and disadvantages of chlorine and UV, using an empirical model to determine the UV dose required for various levels of coliform inactivation. The report also includes cost information and a comparison of chlorination/dechlorination and UV systems (WERF, 1995). Studies in San Francisco, California, indicated that suspended solids play a major role in UV efficiency. This included the finding that, as the concentration of particles 7 mm and larger increase, the ability to achieve acceptable disinfection with UV decreases. Thus, filtration must be optimized to manage this problem (Jolis *et al.*, 1996).

The goal of UV disinfection in reuse applications typically is to inactivate 99.999 percent or more of the target pathogens (Swift *et al.*, 2002). The 2000 National Water Research Institute (NWRI) guidelines provide detailed guidance for the design of UV systems that will achieve high-level disinfection to meet some state standards for public access reuse. The 2000 NWRI guidelines also include a well-defined testing protocol and validation test as a means to provide reasonable assurance that the domestic wastewater treatment facility can meet the high-level disinfection criteria (NWRI and AWWA, 2000).

The Bethune Point WWTP in Daytona Beach, Florida, is the largest UV disinfection system in the state of Florida designed for reuse operations. This facility is also the first public access reuse facility in Florida with UV disinfection to be permitted for unrestricted public access (Elefritz, 2002). Placed into service in December 1999, the Bethune Point WWTP UV disinfection system is a medium pressure/high intensity system designed for a dose of 80mW-s/cm^2 (800 J/m^2) to achieve the high-level disinfection standard. The City of Henderson, Nevada water reclamation facility conducted collimated beam studies of a low pressure/high intensity UV disinfection system. The studies demonstrated that the disinfection goal of 20 fecal coliforms per 100 ml was achievable with a minimum UV dose of 200 J/m^2 (Smith and Brown, 2002).

Other disinfectants, such as onsite chlorine generation, gamma radiation, bromine, iodine, and hydrogen peroxide, have been considered for the disinfection of wastewater. These disinfectants are not generally used because of economical, technical, operational, or disinfection efficiency considerations.

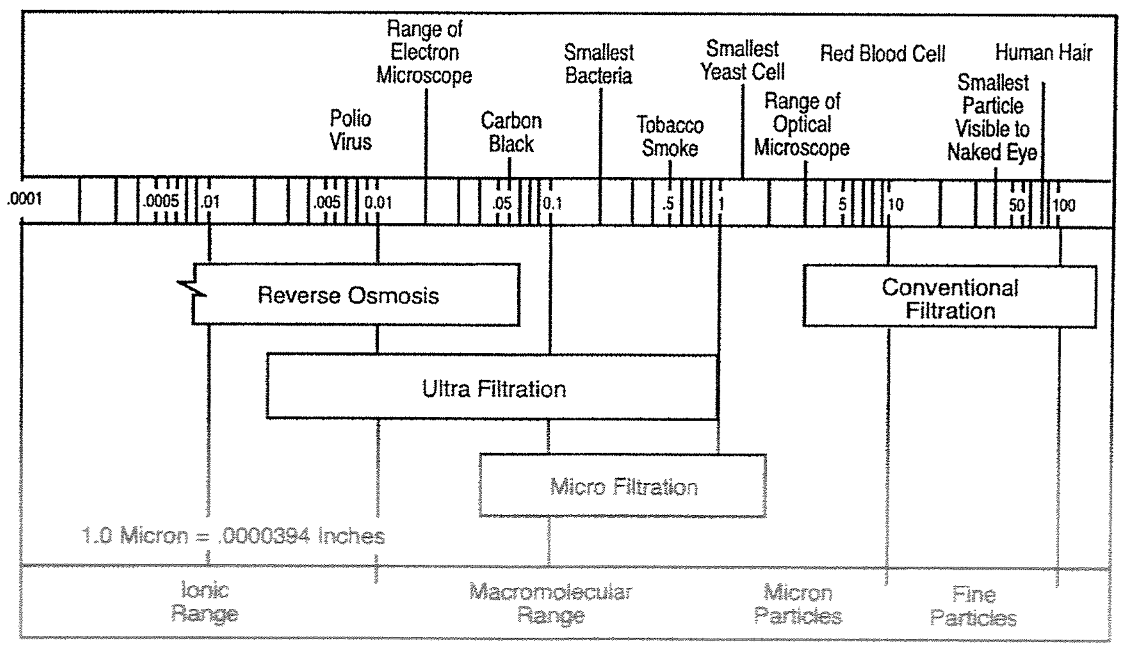
3.4.2.2 Advanced Wastewater Treatment

Advanced wastewater treatment processes are those beyond traditional secondary treatment. These processes are generally used when high quality reclaimed water is needed. Examples include: (1) urban landscaping, (2) food crops eaten raw, (3) contact recreation, and (4) many industrial applications. Individual unit processes capable of removing the constituents of concern are shown in **Figure 3-11.**

The principal advanced wastewater treatment processes for water reclamation are:

- Filtration – Filtration is a common treatment process used to remove particulate matter prior to disinfection. Filtration involves the passing of wastewater through a bed of granular media or filter cloth, which retain the solids. Typical media include sand, anthracite, and garnet. Removal efficiencies can be improved through the addition of certain polymers and coagulants.
- UV Treatment of NDMA – UV Treatment, considered an Advanced Oxidation Technology (AOT), is the only proven treatment to effectively reduce NDMA. The adsorption of ultraviolet light, even the UV portion of sunlight, by NDMA causes the molecule to disassociate into harmless fragments (Nagel *et al.*, 2001). A study done at West Basin Municipal Water District in Carson, California proved NDMA concentrations were reduced by both low and medium pressure UV (Nagel *et al.*, 2001).
- Nitrification – Nitrification is the term generally given to any wastewater treatment process that biologically converts ammonia nitrogen sequentially to ni-

Figure 3-11. Particle Size Separation Comparison Chart



Adapted from AWWA, 1990